WISCONSIN

GEOLOGY AND PHYSICAL GEOGRAPHY

A View in the Dells of the Wisconsin Photo by Bennett

WISCONSIN

Its Geology and Physical Geography.

A POPULAR ACCOUNT OF THE NATURAL FEATURES AND CLIMATE OF THE STATE FOR STUDENTS AND GENERAL READERS.

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PRESS OF
HENDEE-BAMFORD-CRANDALL CO.
MILWAUKEE, WIS.
1907.

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PREFACE.

The contents of this book represent the substance of lectures presented to students in the Milwaukee Normal School during the last few years. There is little new to science and all discussion of obscure and controverted points has been carefully avoided. The aim of the lectures was to place before students preparing themselves to teach in the state a comprehensive account of its main features, both geological and physiographic. In putting the material into book form for greater convenience an attempt has been made to present these facts so that they may be understood by students of geography in the High Schools and Grammar Schools and at the same time may serve as a general account of the state for general readers. The state holds many problems, and for these more than one answer has been given by different authors; where possible, the different views have been presented, but in most cases the judgment of the most authoritative writer has been given the preference and a single account given without extended discussion. This may savor of dogmatism, but the general reader and the beginning student are in no position to weigh the evidence on technical questions. The student who would weigh such matters judicially must necessarily turn to the original sources for his evidence.

It is hoped that accounts given of the varied features of the state may be found to be accurate and that they may serve the needs of the class for which they were written.

CHAPTER I.

THE GENERAL DESCRIPTION OF THE SURFACE OF THE STATE.

INTRODUCTION.

No state of the union presents features more diverse or of wider interest to the student or traveler than Wisconsin. Within its borders are found rocks so old that they perhaps represent the crust formed on the surface of the cooling globe and with them lie the deposits of the last of all the geological epochs, the glacial deposits of the geological yesterday. In the north central part is the great central massif of crystalline igneous rocks and the highly altered sediments which, tortured and twisted by the mountain making forces, now shelter the mines of iron; in the southwestern portion are the layers of undisturbed sedimentary rocks with the mines of lead and zinc and the quarries of building stone.

Wisconsin is classic ground in the annals of Geology and Physical Geography, for within its borders have been made many steps in settling the important problems in connection with the highly complex science of glaciology and the scarcely less intricate questions of the deposition of the ores of iron, lead, and zinc. Few regions of equal size present so many points of interest and beauty to travelers. The scenery of the state is not so grand as that of a mountainous country, but the unique beauty of the Dells of the Wisconsin, the St. Croix river, and the Devils lake; the gem-like beauty of thousands of small glacial lakes; the solemn grandeur of the evergreen forests, rival in the quiet satisfaction that they give the more majestic beauty of Alpine mountains.

With the exception of a few miles on the northern and northwestern borders, the state of Wisconsin is marked by natural boundaries on all sides but the south. Beginning at the southeastern corner of the state the eastern border is formed by the shores of Lake Michigan and Green Bay as far north as the mouth of the Menominee river. Following up the course of the

Menominee and its tributary, the Brule, the line passes through Lakes Brule and Desert to the west shore of the latter, from thence the line runs directly north and west independent of natural features, to the head waters of the Montreal river and down this stream to the waters of Lake Superior. Passing out to the center of Lake Superior the line remains midway between the shores, recurving to enter the mouth of the St. Louis river. From the mouth the line ascends the St. Louis river to its first rapids and then proceeds as an artificial line directly south until it encounters the upper portion of the St. Croix river. Following down this stream to its junction with the Mississippi it follows the latter to the southwestern corner of the state, which lies directly west of the southeastern corner. The southern boundary is an artificial line lying due east and west and dividing the state from Illinois. The state is bordered on the west by the states of Minnesota and Iowa, on the south by Illinois, and on the northeast by the "upper peninsula" of Michigan; the north and east boundaries are formed by the Lakes Superior and Michigan.

The state lies between 42° 30′ and 47° 10′ north latitude and 86° 45′ and 92° 55′ west longitude, with the lines 45° north latitude and 90° west longitude crossing very near to its center. Its greatest north-south length is 317 miles and its greatest east-west width 290. It has a coast line of 320 miles on Lake Michigan and 132 on Lake Superior.

The rocks of the state are very old; setting aside the thin veneer of glacial drift which was spread over the surface in the geological yesterday of a few thousand years ago, it is probable that the building of the state was completed in the Devonian time (see the geological time scale, p. 18). No rocks of a later time are found within its borders and while it is possible that rocks of a later time were deposited and have since been removed, geological considerations render it rather improbable.

So the state was a completed structure before the coal was formed, before even the simplest verdure had appeared to clothe the hills, before there were animals to tread upon the lands or insects to flit or crawl over the surface. No plants above the lowest types, no air breathing animals, no flying insects were as yet evolved when the highest layers of rock in the state were formed. The duration of the earth since the time when the first readable records were formed is estimated at about one hundred millions of years; the Devonian period closed near the end of the first third of this time and the Glacial period with its ice came only a few thousands of years ago. During all the intervening time, some sixty millions of years or thereabouts, the surface of the state lay exposed to all the degrading forces of

the air and water which sculptured the land into hills and valleys, and would long ago have reduced the whole to the level of the sea had it not been renewed from time to time by elevations of mountain making character in the north and more simple uplifts in the south.

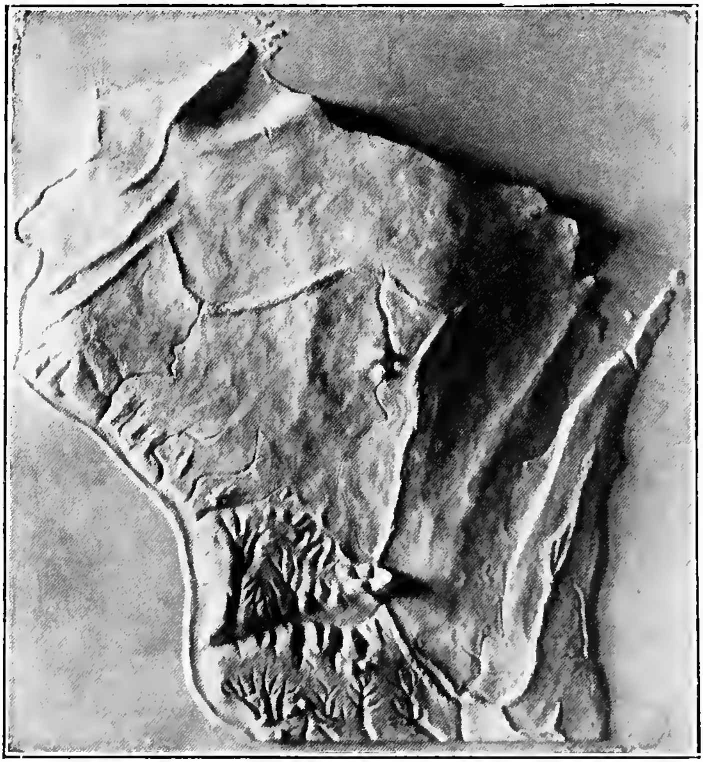
Over the old, old face of the state, scarred by time and the attacks of the elements, the glaciers drew a thin veil of earth, gathered in the north and spread more or less evenly over the land to the south, hiding the wrinkles and scars of time beneath the kindly soil and softening the angles of age into the more rounded contours of youth. But the covering is in many places so thin that both surfaces are recognizable; the older, sculptured in the solid rock, and the younger formed of the close spread curtain of glacial material. This double appearance is emphasized by the presence of the "driftless area," in which the older surface is preserved; a wonderful region far within the area covered by the glaciers yet untouched by the erosive action of the ice and free from glacial deposits, preserving a good picture of what the whole surface of the state must have been before the ice invasion.

This superposition of one set of (glacial) topographic features on another (preglacial) set complicates the orderly description of the state to a marked degree, for the older features are recognizable through the newer and the old still influences the life, development and industries of the state very largely, and independently of the new. It is difficult to draw sharp lines dividing the state into physical regions, for the boundaries dictated by the preglacial conditions and surface are overlapped by those dictated by the glacial and post-glacial conditions. The purposes of description will perhaps be best served by first describing the state as a whole and later attempting to indicate distinct areas.

The surface of the state is broadly divided into two great slopes, a northern and a southern. The northern slope is short and relatively very steep, even precipitous in places, sending its waters into Lake Superior. The southern is much longer and more gentle and bears on its surface the rivers which drain south into the Mississippi and southeast into Lake Michigan; the southern slope is thus subdivided into two slopes by the water parting between the tributaries of the Mississippi and the rivers that flow into Lake Michigan. There are, then, three drainage basins in the state—that of the Mississippi, that of Lake Superior, and that of Lake Michigan; it sends its southern and western waters by one long journey south and southeast through the Father of Waters to the Gulf of Mexico, 2,000 miles distant, and

its northern and eastern waters through the Great Lakes to the Gulf of St. Lawrence, an even greater distance.

Diagonally across the southern slope from northeast to southwest extends a great shallow valley which has played a most important part in the history and commercial development of the state. Existing in part before the glaciers and greatly modified



Photograph of a Relief Model of the State of Wisconsin

but not obliterated by them, the valley is easily recognizable on even the simplest map in the courses of the lower Wisconsin and the Fox rivers. These from the point of their nearest approach to each other flow in almost diametrically opposite directions and empty into different bodies of water, but are perhaps parts of a

disconnected whole. The valley and its contained rivers extending from Lake Michigan to the Mississippi, and broken only by the short and low divide at Portage, opened to the early explorers and inhabitants an easy route of progress across the state; along this passed a train of Indians, French trappers, missionaries and explorers. To the later inhabitants, when the state had become more settled, it brought the dream of an even greater route of travel when the opening of a canal at Portage should place the Mississippi river in direct connection with the Great Lakes and afford a channel along which should pass the products of the Mississippi valley in exchange for those of the great sister valley of the St. Lawrence. But the rapid growth of the railway, coupled with the difficulties of controlling the shifting channel of the Wisconsin river, which can only be conquered when, as described by one disgusted engineer, it is "lathed and plastered," has dispelled the dream, and the rotting timbers and clogged channel of the canal tells that the procession of commerce is gone as completely as the procession of romance before it.*

Across the central portion of the state from east to west is the low lying sandstone area (fig. 8), less fertile in places than the rest of the state, covered by a more scanty vegetation but far from being a waste land and profitless region, for aside from the population that thrives on its surface it is the receiving station, where enters all the water from rain and melting snow which, passing through underground channels, appear again in the famous artesian wells farther south, not only in Wisconsin but even in Indiana and Illinois. North of the low sandstone area lies the highland area of hard igneous rocks, originally covered with pine and evergreen trees, which originated and long supported the great lumbering industries of the state. The soil once freed from its forest covering is found wondrous fertile in spots and the solitude of the early woods is fast giving place to the activities of a busy farming population. The overlying clay deposits of glacial origin have in many places retained the surface waters in swamps and lakes which swarm with fish and the thick undergrowth protects many deer, which attract to the northern portion of the state an army of sportsmen every season. Here also are located the great mines of iron ore.

South of the great sandstone lowland the rocks and soils are more varied and a careful husbandry has detected a large series of soil types and devoted each to the raising of the crop for which it is best fitted, so that southern and eastern Wisconsin can boast of peas and tobacco, sugar beets and potatoes, and many

*R. G. Thwaites' "Down Historic Highways" gives a vivid picture of the canal and the Fox river in their present condition.

other crops, each grown in the most favorable soil. In the southwest the character of the rock changes again and to the products of the soil is added that of the mines of lead and zinc.

The surface of the state and the history of its development will best be explained in detail after an account of the geological structure and history.

CHAPTER II.

THE GEOLOGICAL HISTORY AND STRUCTURE OF THE STATE.

The geological history of Wisconsin has a peculiar fascination in that certain rocks of the northern portion are perhaps among the oldest on the surface of the earth. It has even been suggested that they are remnants of the solidification of the molten material which formed the outer layer of the globe in the first stages of the earth's development and are a portion of the primeval crust. This idea is not supported by all writers; in fact, it is a matter so complex that it can only be settled, if ever, after an enormous amount of material has been collected and after years of study.

Van Hise* gives four theories which are current concerning the origin of these rocks, but all point to their extreme antiquity. "(1) The Archean consists of metamorphosed sedimentary rocks; (2) the Archean is igneous, but of later ages than certain of the pre-Cambrian clastics with which it is in contact; (3) the Archean is igneous and represents a part of the original crust of the earth, and is therefore older than any sedimentary rocks; (4) the Archean is igneous and represents a part of the original crust of the earth or its downward crystallization." He regards the last as the probable explanation, for he says: "This fourth view is offered as a more probable approximation to the truth than any of the preceding."

As nearly as can be made out, the beginning of the North American continent was a great central massif of igneous rocks extending from Alaska to far south of the Great Lakes and northeast into Labrador. The southern end was as far south as the southern limits of the states of Missouri and Tennessee, but the northern portion, within the United States, was early buried by sediments, so that the oldest rocks appear on the surface only as far south as central Wisconsin.

*Principles of North American Precambrian Geology. 16th Ann. Report. Director of U. S. Geol. Survey. Pt. 1.

The earliest of the rocks of this first continent are nearly all igneous in origin, that is, they were formed from the cooling of melted masses of material, lava and the like, which were either poured out onto the surface of the ground in great floods or forced into cracks and rifts, formed by earth movements. Such rocks are the granites, syenites, dolerites and green stones which are so common in the northern part of the state and are almost equally common in the drift covering the southern part. Sometimes the igneous rocks were remelted and moulded over into new forms, in which case they are spoken of as metamorphic. When a mountain mass is being raised by the folding of the earth the crumpling and bending of a great thickness of rock is accompanied by great heat and this—coupled with the great pressure which caused the folding—produces the change known as metamorphism. The common metamorphic rocks resulting from the change of the igneous rock are the gneisses and mica schists.

The recognition of the igneous rocks is a matter of great difficulty, but the larger classes may be determined with some facility after very slight practice. The following suggestions as to the use of field names for rocks is adapted from Chamberlin and Salisbury's geology:

The igneous rocks are divided into three classes. (1) The coarse grained rocks (those in which the crystals can be seen with the naked eye), the phanerites; (2) The fine grained rocks (in which the rock is distinctly crystallized, but so finely so that the individual crystals are not visible to the naked eye), the aphanites; and (3) The glasses.

To the first class belong the light colored, coarse grained rocks, the granites and syenites, and the dark colored, coarse grained rocks, the dolerites. According to Chamberlin and Salisbury the granites consist largely of the minerals feldspar and quartz, with subordinate amounts of hornblende or mica. The syenites consist largely of feldspar, with little or no quartz, and subordinate amounts of hornblende and mica. The dolerites consist largely of hornblende and related minerals, with subordinate amounts of feldspar.

To the second class, the aphanites, belong the basalts, felsites and porphyries. The basalts are fine grained, generally dark colored rocks composed largely of hornblende crystals, but these are so fine that the individual crystal can not be determined without the microscope. The felsites are lighter colored, fine grained rocks. The porphyries are dark or light colored rocks of fine grain, but in which can be seen a considerable number of crystals of large size, much as the raisins appear in a cake.

The third class, the glasses, comprise the lavas, scoria, pumice, volcanic glass or obsidian, etc.

The gneisses and schists which are produced from the igneous rocks by the metamorphic action of heat and pressure do not differ from the original rocks in their mineral content, but in the fact that they have a new or changed form (hence the name metamorphic). They have the minerals arranged in more or less definite layers so that to the uninitiated they present the appearance of stratified, sedimentary rocks, but the layers have been formed by the crystals arranging themselves to present the least resistance to the pressure, and not by the deposition from water. Gneiss differs from mica schist chiefly in the less perfect arrangement of the layers and in the smaller quantity of mica present. Gneisses and schists may be formed from the metamorphism of sedimentary rocks, but this takes place only in extreme cases, and could hardly be determined by any other than the advanced student.

The Archean.—The first great division into which the geological history of the world is divided is called the Archean (see geological time scale, p. 18). Just what went on within the limits of the state of Wisconsin during that time has not been clearly made out and probably never will be perfectly known, for the record is so old, the destructive agents of the air and water have so blurred the story and the later deposits have so obscured them, that they are readable only in small part.

It seems most probable that the original mass of igneous rocks was so long subjected to the degrading action of the weather and of the rivers and waves that it was reduced to the condition of a plain not greatly elevated above the surface of the sea which surrounded it.

A moment's thought will show the reader that no river can lower its valley below the level of the body of water into which it flows, for the carrying and cutting power of the stream depends on the velocity with which it moves and as soon as it flows into a large body of quiet water the velocity is stopped and the load is laid down in the form of a delta. The level below which the land can not be lowered is known as the base level of erosion and is ultimately and for all streams the level of the sea, but any stream flowing into a body of quiet water or even into a larger stream has a local base level which is the level of the water into which it flows and only when the surface of that body of water is lowered will the stream be able to cut down further.

As the velocity of the river is determined by the slope of the land over which it flows, and as it carries its load and does its cutting by virtue of its velocity, it is evident that as the land is cut down toward the base level it will approximate to a plain and the velocity of the stream will diminish, but as the velocity diminishes in just so much will the cutting and carrying power diminish, so that there must come a time when the land has just enough slope to enable the water to run off but will not give it sufficient velocity to carry away any material; this will be before the land has reached entirely to the plain condition, but will be little short of it. Such a gently sloping surface approaching to a plain without quite reaching it is known as a "peneplain" (almost a plain).

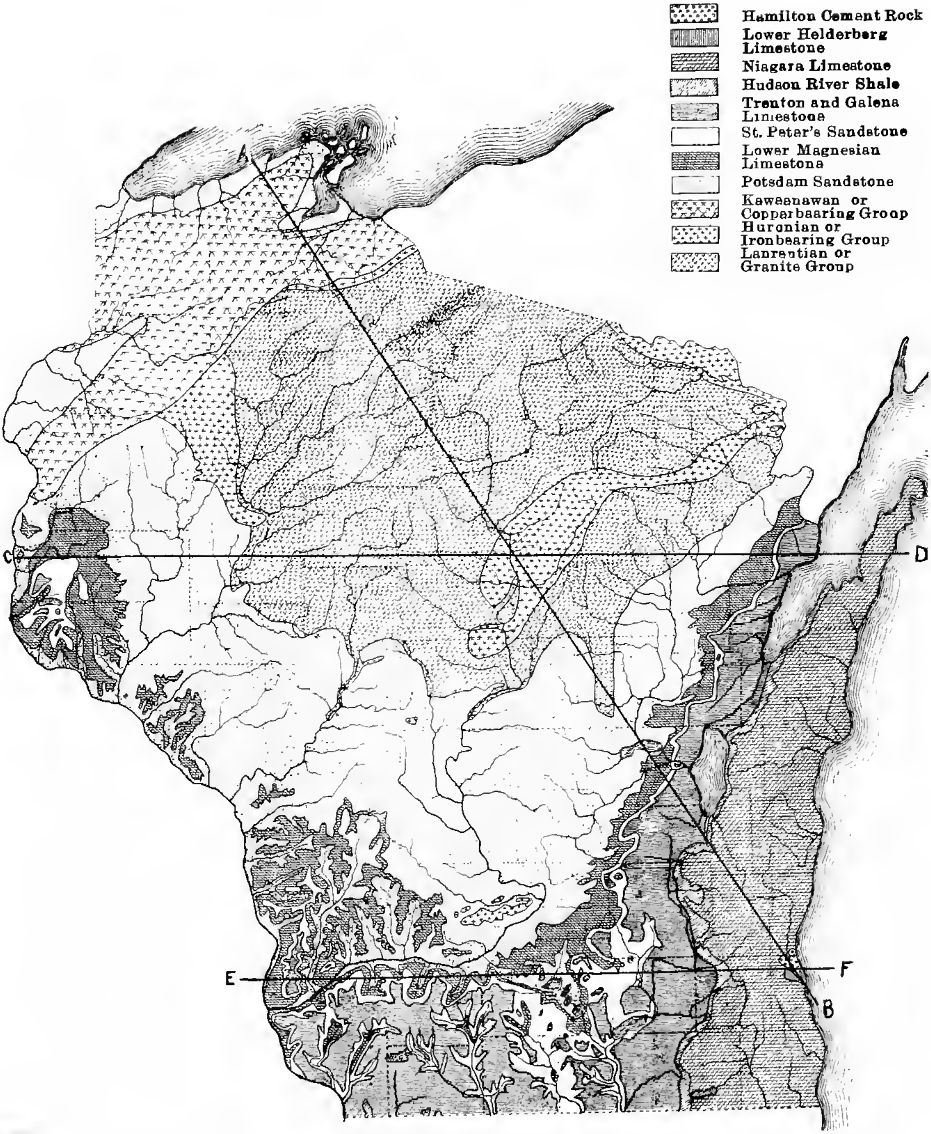


Fig. 1. General geological map of Wisconsin. From the Geological Survey of Wisconsin.

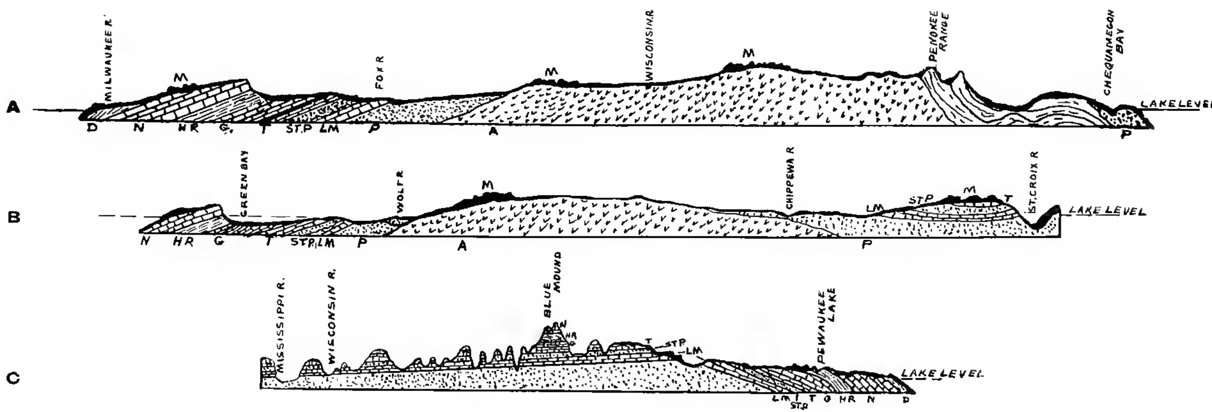


Fig. 2. Sections through the state along the lines indicated on the map, fig. 1. a, along the line A-B; b, along the line C-D; c, along the line E-F. a, Archean; p, Potsdam; l m, Lower Magnesian; st p, Saint Peter's; t, Trenton; g, Galena; h r, Hudson River; n, Niagara; d, Devonian; m, moraine. From Geol. Survey Wis.

GENERAL TABLE OF GEOLOGICAL DIVISIONS

(Representing Approximately 100 Million Years from Archean to Present).

	In the United States.	In Wisconsin.
Cenozoic	Present. Pleistocene. Pliocene. Miocene. Oligocene. Eocene. Transition (Arapahoe and Denver beds).	Present. Pleistocene.
Mesozoic	Upper Cretaceous. Lower Cretaceous (Comanche or Shastan). Jurassic. Triassic.	
Paleozoic	Permian. Coal Measures or Pennsylvanian. Subcarboniferous or Mississippian. Devonian. Silurian. Ordovician (Lower Silurian). Cambrian. Great Interval.	Devonian. Silurian. Ordovician (Lower Silurian). Cambrian. Great Interval.
Proterozoic	Keweenawan. Interval. Animikean or Penokean (Upper Huronian). Interval. Huronian.	Keweenawan. Interval. Upper Huronian. Huronian.
	Great Interval.	Great Interval.
Archezoic	Archean Complex.	Great Granitoid Series. Archean Complex. Great Schist Series (Lower Huronian).

The Lower Huronian.—The material worn down from the surface of the Archean land mass was deposited as layers of sedimentary rocks, sands, clays and even limestones under the waters of the surrounding ocean; the degradation and deposition was accompanied by a general depression of the surface until practically all of the region that is now Wisconsin had disappeared beneath the waves. It is not certain whether all of the state was covered, there being reason to think that some parts in the northwestern part were never submerged. Upon the submerged surface was deposited material worn from shores to the north and east, and this went on until the deposits reached several thousand feet in thickness. The shores of the land which furnished the debris deposited on the ocean border could not have been far beyond the limits of the state, for the majority of the material was coarse sand and gravel which would only have been carried by currents or waves of considerable power and not far from land. These originally loose masses of sand and gravel are changed to hard sandstones and conglomerates, having been cemented by the introduction of lime and iron into hard rocks and further consolidated by enormous pressure and heat.

At the close of the time of degradation, depression and building up of the ocean bottom there came a time of re-elevation of the land over areas whose limits are not precisely known, but which extended beyond the limits of the state. The elevation was accomplished by a series of disturbances such as formed the Archean land; the rocks were thrown into enormous folds and were broken by numerous fractures and these were accompanied by outpourings of enormous floods of lava. The bending of the great thickness of rocks resulted in the production of a great deal of heat, just as a piece of metal may be heated by rapidly bending it in the fingers; this heat softened the rocks and the enormous pressure which caused and accompanied the heat bent the rocks into minor plications and resulted in their profound metamorphism. This metamorphism formed a whole series of rocks, which differ from the original rocks only in the arrangement of the minerals. The igneous rocks became converted into gneisses and mica schists which have the same minerals as the granites and dolerites, but have them gathered into distinct layers, so that the rock at first glance resembles the sedimentaries. The sandstones were converted into quartzites, the shales into slates, and the limestones into marble.

The Archean time ended with the elevation of great mountain masses. The cycle included in the deposition of the sedimentaries around the old Archean masses and the subsequent

elevation of the ocean bottom is reckoned as the second recognizable division of geological time and is called the Lower Huronian or by some authors simply the Huronian.

The Upper Huronian.—Succeeding the elevation which marked the close of Lower Huronian time and accompanying the long continued movements of the earth which resulted in the deformation (folding, bending and fracturing) and metamorphism of the rocks was a long period of degradation, but this did not last so long as in the preceding time nor was the surface of the land reduced to a base-level. Accompanying the period of degradation and following it came a submergence that for the second time placed the surface of the state below the level of the sea. On the bottom of this sea was deposited a great thickness of conglomerates, sands and shales, which were in turn re-elevated, deformed and metamorphosed, passing through a cycle very similar to that of the Lower Huronian. This second cycle is known as the Upper Huronian (Animikean or Peenokean).

The Keweenawan.—The land which was elevated at the end of the Upper Huronian was subjected to a long period of degradation which finally terminated in the complete submergence of the land under the waters of the ocean, which now, for the third time, covered the state. The history of this third sea is not quite the same as that of the two preceding, for instead of a long time of quiet and continuous deposition there were great fluctuations in the level of the ocean bottom with repeated emergence and submergence, resulting in alternate erosion and deposition; so the beds are such as would be deposited at the bottom of a very shallow sea and subject to great disturbance by waves and currents. At the same time as, and probably correlated with the disturbance of the ocean bottom there were great volcanic disturbances on the land, resulting in enormous floods of lava, which covered great areas of the surface. A final movement upward terminated the ocean's possession of the region and a series of faultings and foldings produced a heat and pressure that thoroughly metamorphosed the sedimentary rocks into crystalline gneisses and schists. The rocks of this cycle of deposition and uplift are known as the Keweenawan and are found almost entirely in the northwestern part of the state.

Van Hise has summarized the history of the region as follows:

111. Cambrian.	Lake Superior Sandstone.	
	Unconformity.*	
11. Algonkian.	Keweenawan.	
	Unconformity.	
	Upper Huronian. (Penokee - Gogebic Series.)	Tyler slate. Ironwood formation. Palms formation.
	Unconformity.	
	Lower Huronian.	
	Unconformity.	
1. Archean.	Granites and granitoid gneisses, schists and fine grained granites.	

*The term "unconformity" refers to a condition where the strata of one age or period do not lie parallel to those directly below them, nor do they correspond with them; they do not fit them. Such a lack of correspondence is evidence that there has been an erosion interval between the deposition of the two, that is, that the land was above the surface of the water between the two stages of deposition; or that there was a tipping, tilting, folding, faulting or other disturbance after the first was laid down and before the second. In general an unconformity means that the sequence of deposition has been disturbed and that there must have been an emergence of the land.

The close of the Keweenawan is generally held to mark the close of the second great period of geological time, the Proterozoic or time of first life, for the presence of large deposits of calcium carbonate in the form of limestone and marble, and the presence of carbon and sulphur in the form of graphite and pyrites of iron (fool's gold) indicates the possibility that life was present on the earth even in that early day, for all of these are or may be the direct result of the action of plants and animals. Calcium carbonate is forming in the oceans today as the product of the life and death processes of animals which extract it from the water and build it up into their hard parts, as the corals and shell-bearing animals in general. These hard parts, shells, bones, coral fragments, crinoid stems, etc., are broken up by the waves and ground into a fine calcareous mud which settles to the bottom and hardens into limestone. Carbon and sulphur, as is well known, are essential parts of the bodies of plants and animals. Because of the abundant presence of these elements and minerals which are so closely related with the lives of animals and plants many authors believe that life must have existed earlier than we have any traces preserved in fossils, and by them the time is referred to as Proterozoic (first life) instead of Azoic (no life). On the other hand, it is obvious that all these elements must have existed on the earth before life began and it is very possible, and even probable, that the deposits are due to purely chemical action without the intervention of life. Of course the finding of traces of animals

in the form of fossil fragments would settle the question at once, but it is hardly possible that such frail structures, if they ever did exist, would be preserved through all the changes that the rocks of this age have undergone. The question must thus be left open for future discoveries to decide.

The Great Interval and Cambrian Time.—After the disturbances at the end of Keweenawan time, the elevated lands of Wisconsin were quiet for a long time; so long that the mountains and irregularities were worn down nearly to the level of the surrounding sea, whose border on the south was probably near the present south line of the state. From this low plain of degradation rose several isolated masses which preserved their integrity in part because of their superior initial hardness; such masses occur in the central portion of the state and one great mass farther south is prominent today as the Baraboo Ridge.

During this great period of degradation the land to the north was sinking into a great downward fold of the earth, the Lake Superior syncline,* so that the flat land of northwestern Wisconsin came to be a great island or peninsula surrounded by the sea. On the south the sea border was creeping north, the southern part of the plain was being covered and the isolated masses of upstanding rocks were converted into off-shore islands. (The time used in this leveling of the land with the sinking of the northern and southern borders was enormous, equal to all preceding recorded time at least; it was an interval to be recorded in units of thousands of years, units that can only be appreciated by a distinct effort and after a careful schooling of the mind to the appreciation of the unhurried labors of the natural forces.)

Finally the great post-Keweenawan peneplain was completely or nearly submerged under the waters of a new sea and an era of deposition began; it is impossible to say whether the waters of this sea covered all portions of the state or not, but if any remained permanently above the surface it was only in the high northern and northwestern portions. Far within the area of the crystalline igneous rocks are found today masses of the sandstone lying farther south; these were undoubtedly at one time

*An anticline in the rocks is where the strata, originally horizontal, have been bent by some force, generally lateral pressure, up into an arch so that the strata of the two sides incline or "dip" away (anti) from the median axis. The syncline is just the opposite, the strata have been bent down so that the two sides dip together (syn) toward the median axis. A region where the rocks dip in a single direction is referred to as a monocline.

connected with the larger mass and have been separated by the processes of erosion which have removed the connecting portions. (It is probable* that this sandstone once covered all of the state and the parts free from it have been uncovered from their complete burial.)

This new sea which covered the land was indeed a new sea, for though it was but the extension inward of the same water which had bordered the land from the beginning it was now, far the first time populated abundantly by shore and shallow water living invertebrate animals of many kinds—brachiopods, trilobites, crinoids, etc. Whence this abundant life came we know not; perhaps it was developing in the waters of some other portion of North America or of the world while the main portion of Wisconsin was out of water and not receiving deposits that would preserve the record of its development. In this case the rocks bearing such records have not yet been discovered, perhaps they are buried under the sediments of later seas.

The deposits from this new sea are almost entirely sandstone within the limits of the state. Just as on the Atlantic coast today the deposits on the shores of the ocean where the water is shallow and disturbed by currents and waves are almost entirely pure, clean sand and the mud and silt is carried farther out and deposited in the quieter water, so on the old Wisconsin shore the sand was deposited in a long stretch of shallow water bordering the land and the finer material forming muds and clays were swept out beyond the limits of the state.

The depression that permitted the water to overwhelm the land was continued throughout the duration of the sea, for the deposited sands are in places over a thousand feet thick; sands such as those in Wisconsin could only be deposited in water which is very shallow, not greatly exceeding 100 feet at the most, and so the bottom must have been sinking continuously to permit 1,000 feet of such sand to accumulate. The sandstone varies in different parts of the state, some being harder and some softer, and in places it gives place to a sandy shale; this is just as would be expected in an area of the size covered by the sandstone, for the shallower and more disturbed portions would not have such compacted and consolidated beds, but the deeper and quieter portions would permit the accumulation of fine muds, which would render the sandstone shaly; the regions adjacent to the mouths of rivers would have more silt, so that the best idea of the conditions under which the sand was laid down can be obtained by a careful study of the conditions of a modern ocean bottom.

*Weidman.

The state is described by Chamberlin in the Geological Survey of Wisconsin as represented only by an island of small size surrounded by an open shallow sea, the island growing ever smaller throughout the Cambrian time until it was reduced to very small dimensions or is completely submerged; this is the Isle Wisconsin and on its flanks and around its edges was built up all the rest of the state. Later work has caused the accuracy of this picture to be questioned, but it is of great value to the beginning student.

The time of the sandstone deposition is called the Cambrian; it is the first division of the great period known as the Paleozoic time or time of ancient life. But not all of the Cambrian time is represented in Wisconsin, for during the time a good part of the state was out of water and undergoing degradation while deposits were being laid down in other parts of the United States. The accompanying comparative table will give an idea of the position of the Wisconsin sandstone of Cambrian time:

COMPARATIVE TABLE OF CAMBRIAN DEPOSITS.

	In the United States.	In Wisconsin.
III.	Potsdam, Upper Cambrian.	Potsdam, Upper Cambrian.
II.	Acadian, Middle Cambrian.	Wanting.
I.	Georgian, Lower Cambrian.	Wanting.

Following the deposits of Cambrian time there was a series of deposits in the southern and eastern parts of the state which lie one upon another in an orderly succession around the borders of the land and record the passage of time until the final elevation of the state at the end of the Devonian, which put a stop to further deposition and since which it is extremely likely that the state has never been covered by the waters of any ocean. The orderly arrangement of the strata in an unbroken sequence of deposition from the Cambrian to the Devonian is of importance, for it tells us that through all the time between there was no disturbances of any great amount in the state and that the waters covered its southern portion continuously, only varying in depth and in the character of the life in its depths and on its bottom, with the passage of time and the varying position of the shore line.

The Ordovician Time.—The close of the Cambrian period and the beginning of the Ordovician or Lower Silurian was not marked by any disturbance of the rocks within the borders of the state. The waters of the ocean deepened somewhat over the southern part and there was a consequent change in the

life which inhabited the waters. The deepening of the sea meant a retreat of the shore line, as it was accomplished by a tilting of the earth from north to south. As the shore line retreated to the north the waters over the southern part of the state became clearer, for the debris from the land could not be carried far enough from the shore to pollute them; with the clearing of the water the life changed from forms such as brachiopods, trilobites, and the like which lived upon muddy and sandy bottoms in shallow waters, to corals, which prefer a clear, warm water of greater depth. In consequence the rocks of this time are more commonly limestones and the fossil contents are notably different from the underlying sandstone.

The lowermost layer of the Ordovician, lying directly upon the Potsdam sandstone, is a heavy limestone of variable thickness, ranging from 50 to 250 feet, and is called the Lower Magnesian limestone (see the geological map, p. 16). As indicated by its name the stone contains much magnesium as well as calcium; it is rather a dolomite, Mg Ca $(CO_3)_2$, than a pure limestone. It is very widely distributed over the southern and western portions of the state.

COMPARATIVE TABLE OF THE ORDOVICIAN DEPOSITS.

	In the United States.	In Wisconsin.
Trenton	Hudson River shales.	Hudson River shales.
	(Cincinnati shales.)	(Cincinnati shales.)
	Utica.	Absent.
	Trenton.	Galena and Trenton limestone.
		(Blue and Buff limestone.)
Canadian	Chazy.	St. Peters sandstone.
	Calciferous.	Lower Magnesian.

Following the deposition of the Lower Magnesian limestone the seas shallowed temporarily and there was deposited a layer of sandstone, the St. Peters sandstone, which is a soft, friable rock yielding readily to the attacks of the weather. It has an average thickness of about 100 feet and has almost the same distribution in the state as the Lower Magnesian.

After the shallow seas of the St. Peter's time the sea was again deepened and there were deposited two beds of limestone, the Galena and the Trenton. It is evident that during the deposition of these limestones the condition of the seas was not at all stable, for the rock changes repeatedly from a pure limestone to a shaly limestone; layers of considerable thickness of almost pure calcium carbonate alternating with muddy shales of few inches

in thickness, showing that the depth and purity of the water was constantly changing and that considerable masses of mud were frequently swept into the ocean from the shore.

The Galena is the more solid of the two layers, especially in its upper part, which is very fine grained and compact, breaking with a conchoidal fracture like a piece of quartz or glass and locally known as the "glass rock." Between the Galena and the Trenton is a thin layer of shaly stone verging from brownish to black and becoming carbonaceous, so that it will give off the odor of petroleum on being struck and will even burn with a smoky flame on heating; this is the so-called "oil rock," and it is so persistent between the two layers of limestone that Grant considers that it may be used as a criterion for their separation wherever the two rocks occur in the state. It is in the Galena and Trenton limestones that the lead and zinc deposits of the state occur.

After the disposition of the limestone the seas shallowed and became clouded with the mud of the shore so that the corals disappeared and the shore animals reappeared; the deposits from the impure waters formed a series of soft mud shales and very impure shaly limestone known as the Hudson River or Cincinnati shales. They have a limited appearance on the surface of the state in a line running slightly west of south along the east side of Green Bay and Lake Winnebago and continuing to the south line of the state. The deposition of these shales marks the close of the Ordovician in Wisconsin.

The Upper Silurian.—This period opens in Wisconisn with a series of soft shales called the Clinton shales; it seems pretty evident that the shallowing of the water in the closing years of the Ordovician culminated, in the Lower Silurian, in the production of a low, swampy land (at least in the eastern part of the state) which received into its tidal swamps and lagoons the debris from the higher land to the north and west. The deposits in the swamps and lagoons took the form of a ferruginous mud which in some places occurs in such quantity and of such a degree of purity that it amounts to beds of iron ore and has been mined as such, notably at Iron Ridge, in Dodge county, where it has been taken out on a small scale for a good many years. From the position of this layer directly above the Hudson River shales and because of its similarity to thicker and better developed deposits in the eastern part of the United States it has been correlated with the Clinton iron ore, a mass of ferruginous shales and limestones extending along the western side of the Appalachian mountains from north to south.

COMPARATIVE TABLE OF THE UPPER SILURIAN DEPOSITS.

In the United States.		In Wisconsin.
111. Lower Helderberg.		Lower Helderberg (?)
11. Onandoga (Salina).		Salina (?)
1. Niagara....	Niagara.	Niagara.
	Clinton.	Clinton.
	Medina.	Absent.

Subsequent to the Clinton period the seas deepened and the shore line retreated to the north and west and there was a return of the warm, clear seas which favored the development of great numbers of corals. The response of the corals to the favorable condition was prompt and vigorous, so that the seas swarmed with the coral reefs and masses of the Favosites (honeycomb coral) and the Halysites (chain coral); the destruction of these reefs by the waves formed the coral mud which accumulated on the bottom and hardened to form the Niagara limestone, which in some parts of the state reaches a thickness of 800 feet. The Niagara rocks of Wisconsin are of the same age and general character as those which form the crest of Niagara Falls and from which the name is derived, but in Wisconsin they are much thicker than in the typical locality. According to Chamberlin, the deposition began earlier in the west and continued longer than in the east. The thickness ranges from 450 feet near the south line of the state to about 800 feet in the vicinity of Sheboygan.

The Niagara limestone, viewed as a whole, is readily separable into several layers representing as many distinct phases of deposition, which are not, however, continuous throughout the state. Chamberlin gives the following comparative table for the state:

In the south.	In the north.
6. Guelph beds.	6. Guelph beds.
5. Racine beds.	5. Racine beds.
4. Absent.	4. Upper Coral beds.
3. Absent.	3. Lower Coral beds.
2. Waukesha beds.	2. Lower Byron beds.
1. Mayville beds.	1. Mayville beds.

The lowermost, the Mayville beds, are composed of roughly broken masses of rough, cherty (impregnated with quartz) limestone, with an average thickness of about 60 feet; it is this layer which forms a good portion of the face of the bluff on the eastern side of Green Bay and the eastern side of the basin

of Lake Winnebago. Its outcrop forms the crest of the outer or Niagara cuesta (p. 39) and also formed the capping layer of the Blue and Platte mounds.

"As a whole the Mayville beds may be readily recognized by their thick bedding, uneven structure and the rough, craggy, pitted surface of the weathered ledges, when taken in connection with their position."

This stone forms the crest of Whitney's Bluff, on the east side of Green Bay; further south it has a height of 100 feet at Mayville; it can be traced to the south on the east side of Lake Winnebago, at Hartford, Iron Ridge, etc., continually growing lower until the last trace of a bluff disappears in the town of Ashippun, in Dodge county.

The later beds are of finer grain, forming a white, even textured stone of great beauty and usefulness as a building material.

The character of the sea in which these stones were formed was evidently very different in the northern and southern portions of the state, however, for the Waukesha stone and the stone from the Lower Byron beds and the Coral beds are very different though contemporaneous in origin. The seas of the Niagara period were especially notable for the development of great reefs of coral and it is to the presence of such reefs that the Waukesha, Byron and Coral beds owe their origin.

Regarding these reefs and their development Chamberlin says, Geological Survey of Wis., Vol. 1, p. 183: "At the south there probably began to grow as early as this the most ancient coral reefs yet identified, though their observed development only appears a little later. They probably had their seat upon the coarse underlying Mayville beds, whose texture shows that they were formed in relatively shallow water, to which present coral reef growths are limited. These grew upward through the succeeding strata, developing themselves most characteristically in the Racine beds. For 60 miles or more along the eastern border of the state, and probably extending southward into Illinois, there lay a chain of barrier reefs. They now appear as irregular domes and prominences of rock. Not only were they the habitat of corals of a score or more of different species, but they were adorned by numerous Crinoids and delicate Bryozoans, and enlivened by multitudes of unique Trilobites, while the lowly Mollusks crept over them, and the gigantic Cephalopods dominated the whole.

The individual reefs differed measurably from each other in the prevailing forms of life that dwelt upon them. One of them, now partially exposed near Saukville, presents a rock that is little more than a mass of coral remains imbedded in calcareous sand.

One near Wauwatosa, the best exposed and most widely known, is notable for the abundance of Trilobites, although the fossils are very abundant. At the quarries near Racine, where the reef character is less conspicuous, Crinoids grew in a profusion unsurpassed in these ancient seas, so far as knowledge extends.

These reefs and the adjacent deposits illustrate more beautifully than anything else among the ancient formations the method by which limestone deposits were formed. The reefs themselves are composed of the commingled relics of the life that grew upon them, in all stages of destruction. There may be seen coralline masses standing erect in the rock precisely as they grew, having entirely escaped destruction during their burial in the growing reef. In other instances only remnants of the masses are left, the greater portion having been broken down or worn away. There are detached fragments showing various degrees of wear, and also a coarse and fine detritus, the ultimate product of the comminuting process. These, combined, make up the mass of the reef-rock. There is evidence that some of the material, after having been once solidified, was again broken up by the waves, and redeposited, forming a coarse, brecciated mass. The spaces between such masses are often filled with granular, sand-like material, in which fossils sometimes occur, as though the animals had sought the protection of these sheltered nooks, or as if their remains were driven by the waves into them. Evidences of worn hollows and recesses in the reefs may be found.

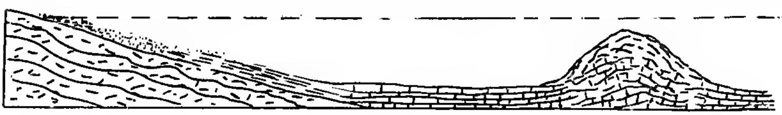


Fig. 3. Cross section of a coral reef, showing the growth of the reef and the building up of the limestone around it from the coral debris broken off by the waves. From Geol. Survey Wis.

"The reefs have not been traced north of Washington and Ozaukee counties; here the water became quieter but contained more of siliceous and aluminous matter, indicating that though the water was more quiet and free from the waves and currents caused by the projecting coral reefs, it was nearer to the mainland of the north."

Above the Niagara limestone there is little belonging to the Upper Silurian in the state, but a few miles north of Milwaukee, just south of the village of North Milwaukee, on the banks of Mud creek, there are exposed a few feet of shaly limestone

lying upon the uppermost layer of the Niagara. This was considered by the geologists of the first survey as equivalent to the lower Helderberg, but Alden (The Delavan lobe of the Lake Michigan glacier, Prof. Paper No. 34, U. S. Geol. Survey) suggests that it belongs to the Salina division of the Onanadoga. As there have been no fossils found in the stone its determination has not been accomplished.

The Devonian.—In a few limited localities in Milwaukee and Ozaukee counties there are deposits of a shaly and impure limestone which burns to an hydraulic cement. This limestone is shown by its position and fossil contents to belong to the Hamilton period of the Devonian time. The areas covered by the Devonian are very limited, but serve to show that the eastern part of the state at least was covered by the seas of that time. A considerable area of Devonian rock is found in Iowa to the southwest of the state, so that it seems probable that the Devonian rocks at one time covered the whole of the southern part of the state and that the part between the deposits on the shores of Lake Michigan and those in Iowa have been removed by erosion. The best occurrence of this stone is in the quarries of the cement mills just north of the limits of the city of Milwaukee, on the Milwaukee river.

The Period of Degradation.—There is no record preserved of any addition to the rocks of the state from the end of the Devonian to the advent of the Glacial Period. So far as can be made out the close of the Devonian witnessed the final withdrawal of the seas from the land of the state and the whole surface lay exposed to the degrading action of the forces of the air, the frost, the solvent action of underground waters, and the constant sawing of the rivers. These forces continued their work of wearing down the land through the long, long time from the Devonian until the glaciers came with their load of transported material from the north, which they spread as a thin veneer over the surface of the land, where it served rather to conceal than to repair the ravages of time and the wrinkles of age.

This last period during which the state was exposed to the ravages of the elements was not nearly so long as some periods of degradation in the earlier times, e. g., the period after the Keweenawan, when the whole surface was reduced almost to the level of the sea, but it was of sufficient length to produce changes of the utmost importance to the geographical and commercial interests of the state, for it permitted the agents of degradation

to work until the land was carved into every form of relief that the structure of the underlying rocks permitted. To the student of the physical geography of the state this period is of the utmost importance, fully equal to that of the geological building which preceded it and the period of glaciation which followed, for in it were produced all the preglacial land forms which influenced so largely the movements of the ice and which are still of so much importance in the development of the state, as they are only partly hidden by the deposits of ice carried material. It is to this period of degradation that we must now turn to learn the causes and the history of the development of the chief surface features of the state.

CHAPTER III.

THE PREGLACIAL DEGRADATION OF THE SURFACE OF THE STATE.

In order to appreciate the effect of the degradation of the state in shaping the hills and valleys, stream courses and uplands, it is necessary to understand: (1) The forces at work in the degradation; and (2) The structure and character of the rock upon which these forces worked.

The work of degradation may be defined as the gradual destruction of the solid rocks and their removal to a lower level, ultimately to a position below the level of the sea. It may be considered as made up of two distinct processes, the loosening of the material and its removal, or the (a) Weathering and (b) the Erosion and Transportation.

The chief agents of Weathering are in the order of their importance: (1) The splitting action of freezing water as it expands on taking the solid form. (2) The solvent action of percolating waters. (3) The unequal expansion and contraction of rocks under changes of temperature. (4) The action of plants and animals as they push or burrow their way into the earth. By far the most important of these is the first.

The chief agents of Erosion and Transportation are: (1) Rivers. (2) Waves. (3) Winds. (4) Glaciers. There are many minor ones, but their work is so small compared to these four that they may be neglected in a general description.

Rivers do their work of sculpture in two ways:—(1) By the direct down-cutting of the stream on its bottom; and, (2) By the removal of the weathered material which is washed into it. The down-cutting is accomplished by the river dragging over its bed an endless procession of fragments which wear down the bottom by constant attrition, just as the saw in the marble works divides the large blocks of marble by rubbing sand back and forth across the stone. This process is known as Corrasion.

The removal of the weathered material involves the widening of the valley, for as the rocks of the sides of the valleys are loosened by the action of frost and the other agents of weathering, the rain and the smaller streams wash the loosened material into the main stream, where it is used in the work of corrasion. The

swifter the stream, the softer the rock bottom and, up to a certain point, the greater the amount of material carried, the faster will the stream cut down its bed and the valley will be deep with steep sides, compared to its width. But if the velocity of the stream is small, or the underlying rocks hard, or if the load is so great that the stream must use much of its energy in carrying it, the rate of down-cutting will be less than the rate of weathering on the side and the stream valley will be wide with gently sloping sides compared to its width.

Left to itself a river flowing over a mass of rocks of homogeneous character would cut its way straight downward and the valley would gradually widen. At first the stream would flow faster over its steeper slope, but as it gradually cut nearer to the level of the body of water into which it emptied it would reduce the slope of the bed and consequently the velocity until it could no longer wear down the bottom as fast as the sides were worn back, and the valley would begin to change its relative proportions from deeper than wide to wider than deep, and the stream would change from a cutting stream to one that was chiefly occupied in the removal of the material furnished to it by weathering. This change marks the passage from "youth" to "maturity" in a stream; in the first stage the valley would be V-shaped in cross section, in the second it would have a wider bottom and become U-shaped. The widening of the bottom of the valley would be partly due to the retreat of the sides and partly due to the building up of a flat surface on either side of the stream formed by the deposits of the stream in time of flood when it overflowed its banks, hence the flat surface on either side is commonly referred to as the "flood-plain." Through this flat land the river with its diminished velocity flows in an irregular course, the curves and windings of the stream being expressions of its effort to pass round obstacles that in its younger stage of greater velocity it would have removed.

If the river flowed over a series of horizontal layers of differing degrees of hardness instead of over a mass of homogeneous rock it would pass through practically the history described above, but there would be a slight difference, it would cut straight downward as before, but the shape of the valley sides would be rather different as the harder layers would resist longer and stand out in bluffs and the softer layers would weather into long, gentle slopes. When a hard layer is exposed on the side of a valley its superior hardness causes it to resist longer and to present an abrupt face, its retreat is largely determined by the wearing away of the softer material below, which, as it yields to weather, permits the harder superimposed layer to be under-

mined. The withdrawal of support causes the harder layer to break off and form a new vertical face farther back, which will persist until it is undermined in turn. Thus the hard layer will always stand out as a prominent bluff on the side of a valley.

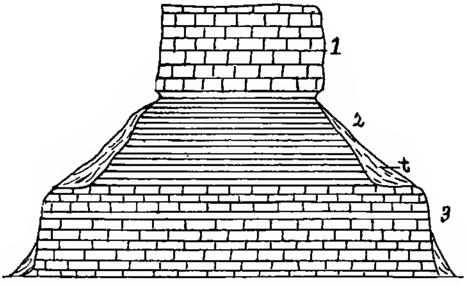


Fig. 4. Section of a bluff in horizontal rocks, showing the steep and gentle slopes formed by the hard and soft layers. 1 and 3 are hard and 2 is soft; t is the talus slope.

The softer layers yield readily to the attacks of weather and retreat as fast as the harder protecting layer above is removed and exposes them; the debris from the wear of the upper portion of the soft layer washing down onto the lower part of the same layer forms a mass of loose fragments, talus, which protects that part from the attacks of the wearing agents. Thus the soft layer worn above and protected below gradually forms a long, gentle slope.

In a country where a series of originally horizontal layers of alternately hard and soft rock have been tilted by some earth movement so that the edges of the layers appear, "outcrop," on the surface the rivers would develop a very different form of relief.

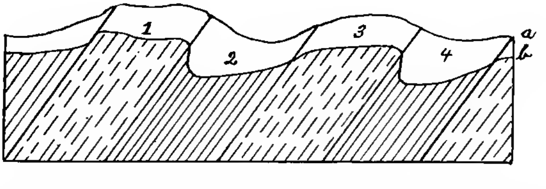


Fig. 5. Cross section showing the outcrop of tilted layers. The surface has been eroded by rivers subsequent to the tilting. a, the original surface; b, the present surface. Layers 1 and 3 are hard and layers 2 and 4 are soft.

Figure 5 shows how the edges of such upturned layers would appear on the surface in long parallel belts or lines. A river running on the surface parallel to the outcrop of the layers and following the ordinary laws of river development would deepen its valley in the softer layers and leave the harder standing up as ridges. The height and prominence of such ridges would be determined by the angle at which the rocks appear on the surface and the thickness of the layers. The more nearly horizontal the layers the less prominent would be the resultant ridge. In Figure 5 the layers 1 and 3 are supposed to be hard, and the layers 2 and 4 are softer; the rivers running parallel to the outcrop would gradually lower the softer layers into valleys with the harder layers standing up as ridges between them. If the layers were more nearly horizontal the river working gradually sideways down the slope of the strata would cut towards the harder layer, forming it into a bluff and leaving the other side of the ridge formed in the softer rocks as a low and gentle slope (fig. 9, p. 40). Such ridges with one slope sharp and steep and the other long and gentle are known as Cuesta ridges. Such a ridge with a river at its foot will have a tendency to be perpetuated through all the stages of degradation.

In a valley where the amount of weathered material is small compared to the carrying power of the stream, i. e., where the stream is able to quickly carry away all the material which is washed into it, the sides of the valley, in horizontal strata would be worked into a series of steps by the alternate appearance of bluffs and slopes due to the presence of harder and softer layers; but where the amount of weathering is so large compared to

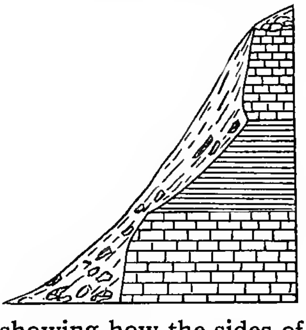


Fig. 6. Section showing how the sides of a bluff may be covered and masked by the accumulation of talus when the river does not carry away all the material that is afforded by weathering.

the carrying power of the stream, that the stream is unable to remove all the loose material, the sides of the hill would be buried in the debris furnished by the weathering and the sides of the valley would assume the form of a rounded slope with the hard rock appearing only at intervals or not at all.

A series of rivers running in all directions over such a region of horizontal strata would not be guided in any wise by the layers, but would cut straight down on the bottoms of their channels whose original direction was determined entirely by the accident of surface conditions; the result would be, that as the valleys became deep the region would be cut up into a number of isolated blocks of land with no definite arrangement of size, position or direction. This is the exact condition of the southwestern part of the state where the Blue and Platte Mounds, the Military Ridge and the uplands between the Platte, Pecatonica and Sugar rivers are conspicuous examples. (See photograph of the model of Wisconsin, p. 10.)

The Ancient Coastal Plain of Wisconsin.—The shores of all the continents today present a very similar appearance to those of Wisconsin in the early stages of its building. They are surrounded by an area of gradually deepening, shallow water which extends out from the water's edge for varying distances, but which terminate by a sudden deepening at about the point where the water reaches a depth of 100 fathoms (600 feet). The area of shallow water is known as the Continental Shelf, the area of sudden deepening is called the Continental Slope, and the deeper portion of the ocean beyond, of an average depth of two and one-half miles, is referred to as the Oceanic Plateau. The continental slope is regarded as the true

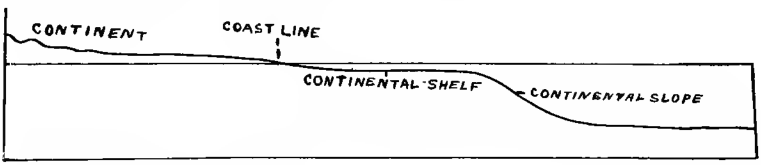


Fig. 7. Profile showing the relation of the continental shelf to the land and ocean.

edge of the continent and the continental shelf is potentially a portion of the land, for it is elevated and depressed, geologically speaking, today and tomorrow, and the deposits upon it are the debris of the land. When a portion or all of the continental shelf

is raised above the surface of the water the flat plain resulting is referred to as a Coastal Plain.

Upon the continental shelf are deposited the sands, clays and limey muds that become the sandstones, shales and limestones of the coastal plain when the land is elevated. The deposits from the land rarely reach beyond the edge of the continental shelf and the deeps of the ocean are rarely raised to the surface to form land, so that there are few rocks that can be recognized as formed of deep water deposits.

It is in this wise that all the sea coast portion of the eastern tier of states has been formed. The "Atlantic Coastal Plain," lying between the sea and the foot of the Appalachian Mountains, was at one time under shallow water and was built up of the debris from the degradation of the Appalachian Mountains just as the bottom of the ocean adjacent to the present coast line is receiving deposits today.

In the alternate elevations and submergences the State of Wisconsin went through much the same history as the Atlantic Coastal Plain; the seas surrounding the old Archean land mass were mostly so shallow as to be regarded as a continental shelf and on their bottoms were laid down the debris from the land in the form of clays, sands and calcareous muds which, when the land was elevated, were hardened into the shales, sandstones and limestones of the state. The similarity in origin and history between the State of Wisconsin and the Atlantic coast is very apparent; only our state passed through its history millions of years ago and the Atlantic coast has still to complete its cycle of development. Wisconsin has very properly been described by Davis as an "ancient coastal plain."*

A coastal plain may result from the elevation of the continental shelf in two ways. (1) Either it may be raised horizontally upward by a single direct movement of the earth, which will result in a flat expanse made up of horizontal layers of varying hardness; or (2) it may be lifted by a single or successive movements so that its inner landward end is higher than the outer; this will cause the layers to be tilted in the ground and the edges will appear on the surfaces as successive parallel belts. Compare figure 5. As soon as the coastal plain appears above the surface of the water it is exposed to the degrading forces of nature and the rivers wear down into it according to the laws explained

*Technical objections have been raised to the use of the term "coastal plain" for Wisconsin, and while these have great weight they seem to be occupied with a close definition of the terms. The use of the comparison seems of so much value that in the mind of the author it outweighs the objections, and so the term is retained.

above, sculpturing the land into isolated blocks if the layers are horizontal or elongate cuesta ridges if the layers are tipped.

The rocks of southern and eastern Wisconsin present illustrations of both kinds of coastal plain; in the south and west the

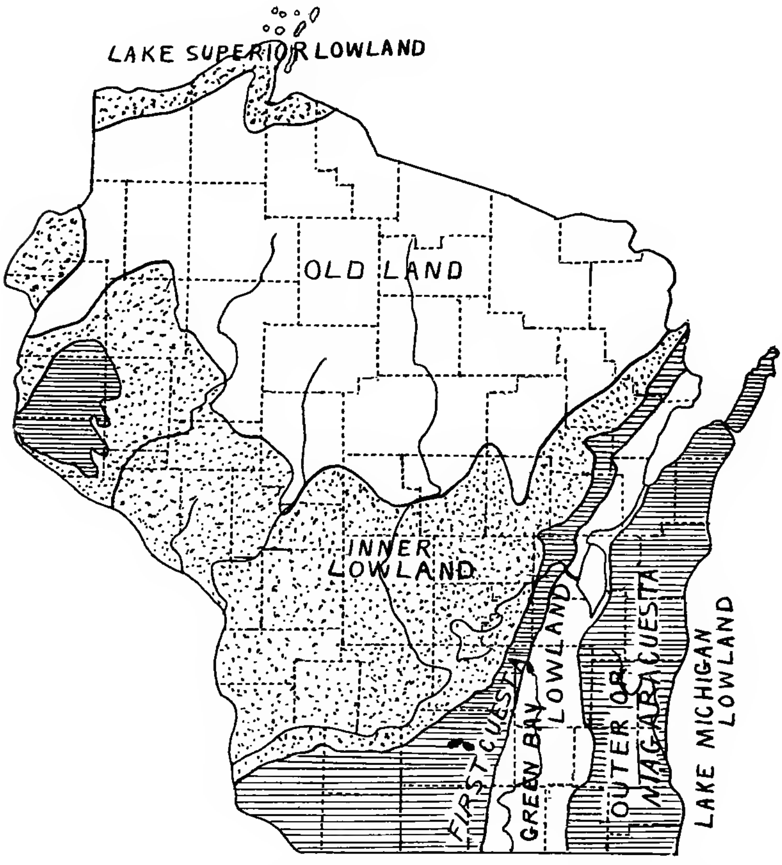


Fig. 8. Map illustrating the ancient coastal plain of Wisconsin. For sections see figure 2. The Old Land is formed of the Archean, the Inner Lowland and the Lake Superior Lowland of the Potsdam sandstone, the First Cuesta of the Lower Magnesian limestone, the Green Bay Lowland of Hudson River shales, the Niagara Cuesta of the Niagara limestone, the Lake Michigan Lowland of Devonian limestone.

layers are nearly horizontal, and in the east they dip away from the old land mass on the north and west. (Figs. 2a, b and c.) The layers of hard and soft rock alternate; the Potsdam sandstone, the St. Peter's sandstone, the Galena limestone and the Hudson river shales are softer and the Archean crystallines, the Lower Magnesian, the Tienton limestone and the Niagara limestone are harder.

In accordance with the principles of erosion described above the tilted rocks of the eastern portion of the state have been sculptured into long cuesta ridges with their steeper faces toward the Old Land to the north and west and separated by lowlands; the horizontal rocks of the southern part have been sawn apart into isolated blocks. This general conception of the degradation of the state controlled by the structure of the underlying rock will enable the student to get a better understanding of the details of different portions.

The map, figure 8, shows the surface conditions broadly. The Potsdam sandstone lying directly upon the Archean rocks has yielded rapidly to the degrading forces and has been worked out into a broad lowland over the central portion of the state. The fact that the outcrop of this porous sandstone has been reduced to a lowland and that below the surface it slants away to the south and east below the impervious Lower Magnesian limestone is the important and determining factor in the presence of the artesian waters of the southern part of the state and of Illinois and Indiana as well. This depressed area is the Inner Lowland of Wisconsin.

Overlying the soft Potsdam sandstone is the harder Lower Magnesian limestone; formerly it extended much farther to the north but a good portion has been removed in the making of the inner lowland. The outcrop of the limestone is a low cuesta ridge with its steeper face to the west and north. It does not show as a bluff on the surface because it is largely obscured by the covering layers of glacial drift, but its course is marked by the presence of a line of gently rising hills from the north side of which the limestone projects at intervals. The course of this ridge is through Marinette, Oconto, Shawano, Outagamie, Winnebago, Green Lake, and Columbia counties. In the last named county the rocks have become nearly horizontal, so the rivers no longer recognize it as a determining factor in their course. North of the lower Wisconsin river, in the triangle between it and the La Crosse and Baraboo rivers, the Lower Magnesian limestone appears capping the tops of hills of horizontal rock, but because of the horizontality the hills are isolated blocks, not continuous ridges. South of the Wisconsin the Lower Mag-

nesian is covered by the rocks of higher formation and is nearly horizontal, but there is a slight dip to the south; this region is a distinct highland, deeply trenched by the rivers which run over it in an irregular manner, for there is not slope enough to the rocks to determine their course, but on the north the edge of the highland is marked by a steep bluff which faces to the north and overlooks the Wisconsin river which flows at its foot. The steep face has been formed by the Wisconsin river shifting slowly to the south, following the slight dip of the layers as it wore out its bed in the soft Postdam sandstone. The crest of this bluff is the celebrated Military Ridge, so called because of the military road that ran along in the early days of the state. It is marked today almost exactly by the course of the Chicago and Northwestern railroad from Madison to Dodgeville. This is the inner or first cuesta.

Overlying the hard rocks of this cuesta are the softer rocks of the Galena limestone and the Hudson River shales. In the eastern part of the state these have been excavated into a long lowland parallel to the inner cuesta, running through Marinette, Oconto, Outagamie, Calumet, Winnebago, Brown, Fond du Lac, Dodge, Jefferson, Rock and Walworth counties. The course of the lowland is marked very plainly by the position of Green Bay, the Lower Fox river, Lake Winnebago, the Horicon marsh and the Rock river as far south as Watertown. As in the inner lowland and the first cuesta the northern end where the rocks are most sharply tilted is the most clearly defined. The valley of the Lower Fox river is excavated in the soft Cincinnati shales,

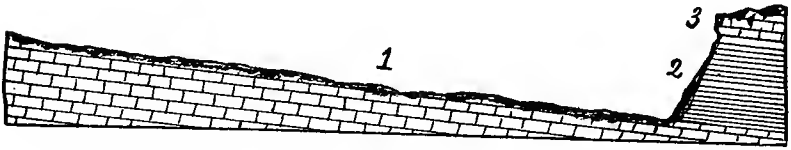


Fig. 9. Section across the valley of Green Bay showing the steep face of the Niagara Cuesta capping the soft Hudson River shales in which the valley is excavated, and the gentle slope of the First Cuesta which form the western shore of the bay. 1. The Galena limestone. 2. The Hudson River shales. 3. The Niagara limestone. From the Geol. Survey Wis.

so that it has very low walls on the west and the bottom is very broad, but the eastern side is marked by the abrupt cliffs of the

steep face of the outer cuesta formed by the overlying Niagara limestone. The whole of the outer, or Green Bay, lowland has the same steep face of limestone from the extremity of Green Bay on the north to a point nearly west of Milwaukee on the south.

The east shore of Green Bay is formed by a line of bluffs from 100 to 200 feet high on the average, but reaching as much as 400 feet in places; these bluffs are nearly vertical and have been sculptured by the weather into peaks and pinnacles, isolated crags and bluffs that give to the shore a unique beauty. South of Green Bay on the east shore of Lake Winnebago and as far south as Horicon in Dodge county the outcrop of the limestone still forms a ridge though much reduced in height. It is traceable in the local names, Winnebago ridge and "the ledge." Farther south the lowland area is less apparent and the ridge forming its eastern face becomes lower until in the town of Ashippun in Dodge county, about opposite Milwaukee, it disappears. The ridge with its steep western face is known as the second or Niagara cuesta; its eastern face is a gentle slope to the shores of Lake Michigan, although the surface appears far from gentle in many places, being covered by the highly irregular superficial deposits of the great terminal moraine. The eastern slope gradually broadens from the northern point of Door county, where the waters of Green Bay and Lake Michigan meet, to the southern edge of the state, where it is about 40 miles wide.

The effects of the great period of post-Devonian erosion was not confined to what is now the limits of the State of Wisconsin, but had a great deal to do with the development of the basins of Lakes Michigan and Superior. The origin of the Great Lakes is perhaps still debatable, but there is little doubt that the site of the present basins of Superior and Michigan were occupied before the ice time by rivers comparable in size to that of the Mississippi as it existed before the glaciers modified its course. It is at least suggestive that Lake Superior lies in a synclinal trough which was once filled, or nearly so, by soft Potsdam sandstone, the same which forms the inner lowland in the central portion of Wisconsin, and that Lake Michigan lies in a trough of soft Devonian limestone and shale which occupies the same position with regard to the Niagara cuesta that the Green Bay lowland of Wisconsin does to the inner cuesta. They were both easily eroded areas that without doubt had felt the effect of the long period of degradation, and the northern basin was probably the site of a great lowland similar to the inner lowland on the south, and the eastern basin was simply a great north and south lowland between the hard Niagara below and on the west and

the hard Carboniferous limestone above and on the east, the rock of the eastern shore of Lake Michigan.

Far to the west in the Platte and Blue Mounds we have evidence of the former extension of the Niagara limestone over the southern portion of the state, for the tops of these mounds, many feet above the surrounding country, are capped with it and the underlying formations show in the sides of the mounds; evidently the rocks of the Niagara period at one time covered all the intervening part of the state and have been removed by the processes of degradation, up to the present limits of the cuesta.

In a very broad way this is the history of the development of the surface of the state before the invasion of the ice stopped its farther degradation and obscured its features; only in the Driftless Area, where the ice failed to go, we have a priceless monument of ancient times preserved to show what would have been the condition of the rest of the state had there not been an Ice Age.

CHAPTER IV.

ARTESIAN WATER.

Artesian wells are one of the most prominent natural features of the state and no description of its physical geography would be complete that did not contain a reference to them. In the first volume of the first Geological Survey of the state and in the Fifth Annual Report of the Director of the U. S. Geological Survey, Chamberlin has discussed in much detail the conditions necessary for artesian wells and has explained their peculiarities in Wisconsin. The following is taken very largely from his reports:

"To obtain a simple and clear idea of the nature of most of our Wisconsin artesian wells, picture to the mind an open, porous stratum, through which the water can readily pass, lying between two others that are essentially water tight. Suppose the beds to be moderately inclined, so that on one side their edges come to the surface (except that they are usually covered with soil and other loose surface material), and that on the other they dip down to great depths, and either come to the surface at a distant point or else terminate in such a way, or take on such a nature, that the water cannot escape in that direction, as illustrated in the accompanying figure. Now picture the surface waters derived from rainfall as penetrating the porous bed and filling it to the brim. That all such beds are full to within a comparatively few feet of the surface we know from our ordinary wells, which find an inexhaustible supply in them without usually going below the main valleys. Now it is manifest that if such an inclined bed, so filled with water, be tapped at some lower point by a boring, the water will rise and flow at the surface, because of the higher head in the upper edge of the bed, and if the surface waters continually supply the upper edge as fast as the water is drawn off below, the flow will be constant.

From this simple conception we may draw out the leading conditions upon which the artesian flows depend, which may be stated as follows:

1st. There must be a stratum sufficiently porous to permit a ready entrance and flow of water through it.

2nd. There must be an impervious bed below to prevent the escape of the water downward.

3rd. There must be a like impervious bed above to prevent the escape upward, for the water, being under pressure from the head, would otherwise find relief in that direction.

4th. All these beds must form a basin, or at least be inclined, so that the edge at which the waters enter will be higher than the surface of the well.

5th. The edge of the porous stratum must be suitably exposed so as to take in a sufficient quantity of water to afford an adequate supply.

6th. To furnish this supply there must be an adequate rainfall.

7th. There must be no escape for the water at a lower level than the surface of the proposed well.

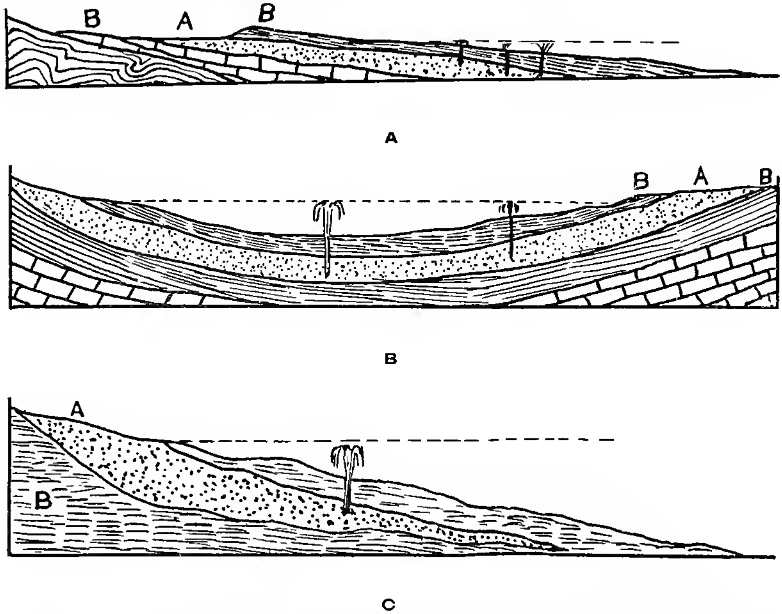


Fig. 10. Section showing necessary conditions for artesian wells. A, the porous layer; B, the impervious layer. The dotted line represents the height to which the water would rise if free. a, The conditions of artesian wells on a coastal plain; this is the condition in Wisconsin; b, The conditions in an artesian basin; c, The conditions in the drift; this is the origin of many shallow artesian wells in Wisconsin and elsewhere. Compare the figures showing sections of the state. From the Geol. Survey Wis.

These may be considered severally and then we may pass to some of the special practical questions involved.

1. The Porous Beds.—The porous stratum in Wisconsin is usually a sandstone. In a few instances flows are derived from limestone strata, as in the case of the wells at Manitowoc. In such cases the water has probably formed underground channels of solution—"veins" of water in quite an appropriate sense. As the position of these cannot be determined beforehand, there is no certainty of striking them, and hence they cannot be relied upon as sources of flow. Experience seems to show that the chances of striking them are quite small. The sandstone beds, on the contrary, are continuous sheets underspreading large areas, and may almost certainly be struck at the proper depth. They are, furthermore, usually so porous that there is little liability of passing through them without encountering at least a moderate supply of water, where other conditions are favorable. The St. Peter's and Potsdam sandstones are our great water bearing strata. The latter is fortunately divided into three separate water bearing horizons by the Mendota limestone and shales, and by a stratum of shale lying lower down. These are not always present, however, but on the other hand, there are, at some localities, other impervious beds that serve a like purpose.

Besides these ancient sandstones there are porous beds of sand and gravel in the drift deposits above the rock, some of which are available as sources of flow; but these are local. * * *"

2. The Confining Stratum Below.—This needs consideration only in special cases and will not be discussed here.

3. "The Confining Stratum Above.—It is much more important to give careful attention to the strata that overlie the water bearing bed than those below, for the water, being under pressure, tends to rise through them, and if they are in any degree penetrable, the water will, to that extent, escape and relieve the pressure and reduce or prevent the flow. Our most nearly impervious rocks are clay shales, such as those of the Hudson river formation. Our limestones, where they are present in considerable thickness, serve as reasonably good confining beds. * * *

4. The Inclination of the Beds.—The water bearing bed and the confining strata above and below must be inclined so that the edge that comes to the surface shall be higher than the portion under the proposed well, else there would be no elevated source of supply for the flow. The ideal conditions are

furnished when they sag in the center with upturned edges so as to form a basin. The water then enters the edges of the porous stratum and fills up to the level of surface drainage at its edges. If, now, this be penetrated somewhere toward the center of the basin, at a point lower than the edges of the strata, the water will rise to the surface.

But it is not really necessary that the beds form a basin. If they are inclined so as to expose their edges on one side, and if the porous bed is blocked up by any means in the other direction, so that the water cannot escape, a flow may be obtained without regard to what may be the position of the opposite edge. It is highly probable that our sandstones, as they pass off from the old shore belt along which they were formed into what was then the deeper part of the ocean, gradually changed from coarse, open sandstone to fine-grained rock, clay, shale, and possibly limestone, and so cease to be readily permeable to water.

Practically, in Wisconsin, we have to deal only with such inclined strata. Our beds dip eastward, southward and westward from the Archean core and central axis of the state, as explained in the Historical Geology, and only reappear at distant points, as in Canada, the Alleghanies, Missouri, or the Rocky Mountains. But it is scarcely probable that our sandstone strata continue as open porous beds throughout such an extent, unless perhaps in the case of the Potsdam sandstone.

5. The Reservoir, or Fountain Head.—The reservoir is simply the water contained in the porous stratum above the level of the point of flow, or, in other words, the water in the marginal portion of the water-filled stratum. * * * This is supplied by the surface rainfall, and this leads us to the consideration of two additional topics: (1) the collecting area, and (2) the rainfall.

6. The Collecting Area.—If the porous bed is thin, and comes to the surface at a considerable angle, its edge will not occupy much area at the surface, and will, consequently, not receive a large supply of water from rainfall and cannot be depended upon to deliver large quantities. On the other hand, if the thickness is considerable, and if the stratum comes to the surface at a low angle, so that its beveled edge is wide, it will have a considerable extension at the surface, and will consequently present a large collecting area, and, so far as that is concerned, will be competent to deliver a large supply of water. The Potsdam sandstone of our state has a very large surface extent on the central arch of the state, and is exceptionally well situated for receiving into itself an enormous supply of water.

Hence any well so situated as to draw upon this supply will not lack for a sufficient accumulation at the fountain head. If it fails it will be for other reasons. The St. Peter's sandstone is

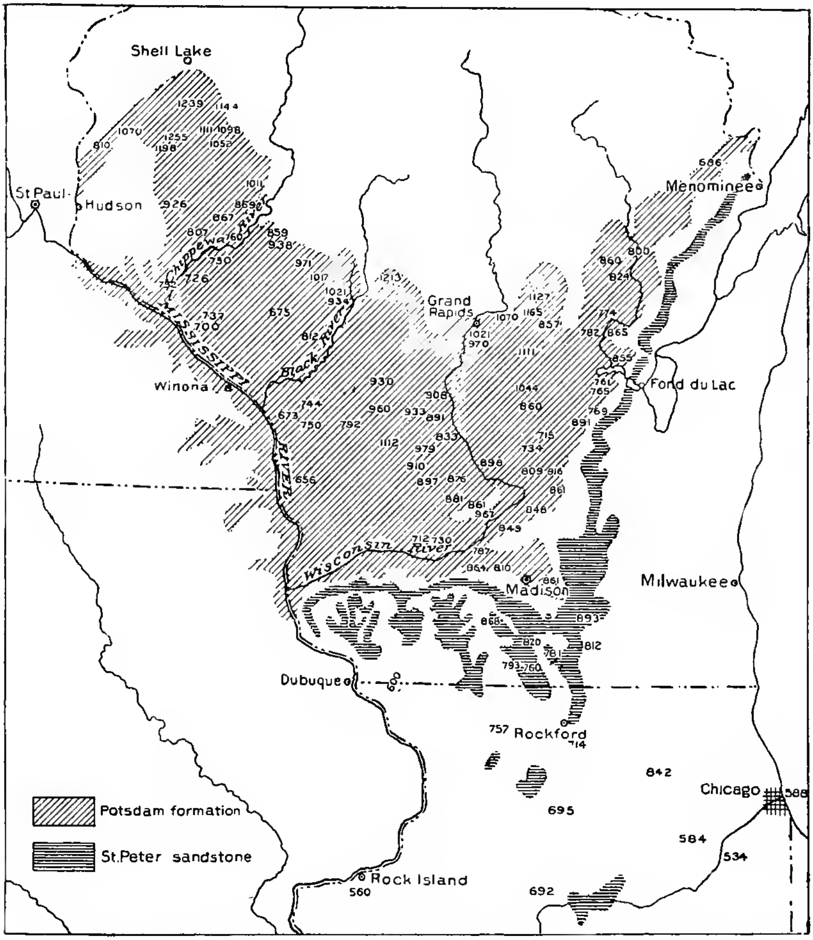


Fig. 11. Sketch map showing the outcrop of the porous Potsdam sandstone and St. Peter's sandstone in Wisconsin. These are the receiving stations where enters the water of the artesian wells, not only of Wisconsin but of good portions of Illinois, Indiana and northeastern Iowa. It will be noticed that the larger collecting area is the Inner Lowland. From Water Supply and Irrigation Paper, 114 U. S. G. S.

thinner and occupies less space at the surface, but with our moderately large rainfall it takes in a very considerable amount, one which is adequate for all ordinary purposes.

7. Rainfall.—With an average precipitation of about thirty inches per annum, fairly well distributed throughout the year, the strata are kept full to overflowing, as the surplus that finds its way out to the surface in springs, or through porous soil, testifies, as do also ordinary wells in the collecting area."

8. Escape at Lower Levels.—This does not affect the wells of Wisconsin in any great degree.

"Areas in Which Success Is Probable.—The height of the outcropping edges of the Potsdam and St. Peter's sandstone having been ascertained by the survey, it is possible to map the state off, as it were, into districts (1) in which the probabilities of securing flowing wells are sufficiently great to justify the attempt to secure them, and (2) into others in which the probabilities are so small as to make the expenditure of time and means in such attempts altogether unjustifiable. Between these are regions in which the favorable and unfavorable conditions are nearly balanced, and no very decided opinion of the result can be expressed beforehand, because sufficiently exact knowledge of the conditions cannot be secured.

The areas of favorable probabilities are as follows: 1st, a belt along Lake Michigan. In Vol. II., the following opinion was expressed (p. 168): 'Near the lake level the chances will be good for the whole of the lake border. From Manitowoc county southward they may be said to be good for elevations not exceeding 100 feet above the lake, to be fair up to 140 feet and but slightly above 150 feet, though perhaps possible in some locations at 200 feet or more.'

2nd. 'The second area consists of the Green Bay valley, from Fond du Lac northward. In the vicinity of Lake Winnebago a flow from either the St. Peter's or Potsdam sandstone cannot be relied on at an elevation exceeding 15 feet above the lake surface, though Mr. Wilds well has demonstrated that it is possible at 50 feet. On the other hand, however, the wells at Oshkosh show that the limit given is the extreme one that is reasonably trustworthy. To the north of Lake Winnebago the limit in altitude descends at about the same rate as the surface of the valley. It must be remembered, however, that the St. Peter's sandstone is not so reliable in the region farther south, where its thickness is more uniform. The Pots-

dam should, however, present reasonable probabilities for the region along the bay, at elevations not exceeding 25 to 30 feet above its surface, with slight chances for greater altitudes.'

3rd. 'The third district lies in the valley of the Rock river. An elevation of 250 feet must be taken as the limit of favorable chances. That a flow at this level is obtainable is shown by the wells at Watertown, Palmyra and Janesville. The St. Peter's sandstone is available for only a portion of the area that falls below that altitude, since, in some parts of it, this formation is deeply eroded by the streams, and its fountain forming possibilities destroyed. Success in these portions will be chiefly dependent on the Potsdam sandstone.'

4th. The fourth district lies along the Mississippi river. In the southwestern part of the state the probabilities are fair for success at elevations not more than 100 feet above Lake Michigan. (The elevation of the Mississippi is here nearly the same as that of Lake Michigan.) The deep valleys of the streams in

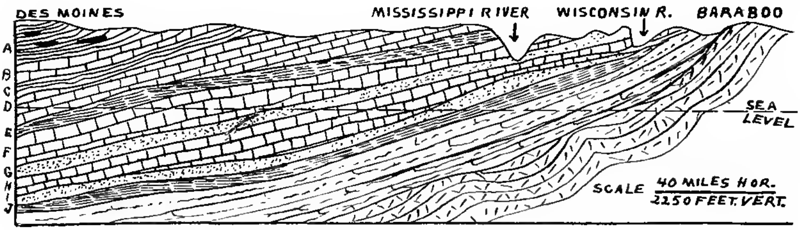


Fig. 12. Cross section of the state from Baraboo to Des Moines, Ia. a, Des Moines formation; b, Mississippian; c, Kinderhook; d, Devonian-Silurian; e, Hudson River; f, Galena-Trenton; g, St. Peter; h, Onoeta; i-j, St. Croix, including Jordan, St. Lawrence and Basal sandstone. From Water Supply and Irrigation Paper, 114.

this region have cut extensively into the confining strata above, and have success less certain than on the eastern margin of the state. Were it not for this, flows could probably be obtained up to 200 feet, and even higher, and such are even now locally secured, as at Sparta. But success at such elevations cannot be relied upon unless the local conditions are exceptionally favorable. Even within a hundred feet of the lake level, partial or total failure has been experienced, apparently through local defects in the confining stratum above the water-bearing beds.

Farther up along the Mississippi the probabilities are less, and attempts to secure flows are not generally to be encouraged.

At low elevations some success may be expected, but the special situation should be carefully considered in each case attempted.

5th. In the sandstone along the shore of Lake Superior it is not impossible that occasional success may be met with.

Doubtful Regions.—In belts bordering these areas, at elevations 25 to 50 feet higher, occasional success may be expected, but the probabilities are poor, and attempts should be made, if at all, with this distinctly in mind.

Drift Wells.—The foregoing, as previously indicated, relates to the wells in the rock beds. There is quite a large class of wells that derive their flow from the drift and depend for their existence upon beds of sand and gravel sandwiched between those of clay, or between clay and the rock below. * * * These are not confined to the districts above indicated and quite independent of the conditions to which the deeper class of wells owe their origin.

Areas of Adverse Probabilities.—In all the higher regions of the state the general conditions are so adverse as to make any attempt to secure a flow altogether injudicious, unless there are known to be special local conditions that are favorable, which are very rare, except, of course, in the drift. As a general rule no attempt should be made at an elevation of more than 300 feet above Lake Michigan.' * * * "Adams, Juneau, Monroe and a part of Wood and Portage counties have beneath their surface and very close to it an exceptionally large volume of water. * * * These counties are underlaid with not less than 100 to 400 feet of sand and porous sandstone, which is now filled with water to from 3 to 20 feet of the surface of the ground and is kept full not simply by the rains which fall upon them, but by an underflow from the more northern counties, whose underlying crystalline and impervious rocks slope gradually toward the south.

Each foot of sand of medium coarseness is capable of holding, when its pores are full, not less than one-third of a cubic foot of water, while the closest ordinary sandstone may hold one-twelfth of its volume. It is therefore highly probable that the water underlying the counties in question is not less than the equivalent of a lake equal to the areas of the counties and having a depth of one-fifth the thickness of the sandstone beds. If these beds are but 100 to 200 feet thick, then the depth of the water is from 20 to 40 feet, from one-half to two-thirds of which might be recovered and brought to the surface with pumps."

CHAPTER V.

THE GLACIAL AGE IN WISCONSIN.

There is no space in a book of this kind to discuss the various theories of the origin and action of the great continental glaciers. Ample descriptions will be found in the various text books of Geology. (Chamberlin and Salisbury, Dana, Le Conte.) But it is perhaps worth while to state very briefly some of the more important phenomena.

A glacier is any mass of ice, consolidated from accumulated snow, that moves by its own initiation over the ground; usually it is of good size, but many masses of small size clinging to the sides of mountains have a motion which brings them within the definition. The motion is very slow, rarely exceeding a few feet a day (as much as 100 feet a day has been recorded, but this is regarded as highly exceptional). Chamberlin and Salisbury state that the ice cap of Greenland probably does not advance more than one foot a day on the average. The origin of motion in the masses of ice is an unsolved problem, but we know it does move, and moves in a manner comparable to that of a very viscous body. The best analogy is that of a barrel of tar which has been overturned on a warm day; the tar streams slowly from the barrel and drags itself stiffly forward over the irregularities of the surface, but eventually accommodates itself to the surface as perfectly as water could and acts upon every inch of the ground. So with the apparently brittle ice, if it is given time it moulds itself in its slow advance to the most intricate irregularities and searches out every exposed surface for its action. Almost every problem of glaciology can be answered, qualitatively at least, by imagining what would be the action of the flowing mass of tar over the same surface.

The rate of the advancement of the ice is determined, according to Chamberlin and Salisbury, by six things. "1. The depth of the moving ice. 2. The slope of the surface over which it moves. 3. The slope of the upper surface of the ice. 4. The topography of the bed over which it passes. 5. The temperature. 6. The amount of water which falls upon it or is carried onto it by drainage of the surrounding land in addition to the moisture supplied by its own melting."

For some reason, probably a combination of elevation of the surface and alteration in the composition of the atmosphere, the climate of the geological period just preceding the present was reduced so much that great quantities of snow accumulated in several places in the northern hemisphere and slowly spread in all directions from these centers. It is a great mistake to suppose that the ice of the glacial time accumulated at the north pole and spread evenly to the south in all directions; instead the ice accumulated in distinct areas rather far south and spread north as well as east, west and south. In North America there were three such centers, an eastern just east of Hudson's Bay supporting the Labrador ice sheet, a middle just to the west of Hudson's Bay from which spread the Keewatin sheet, and a western in the mountains about the same latitude, supporting a smaller, Cordilleran sheet (see fig. 13). It is with the easternmost of these, the Labrador sheet, that we have most to do, for, with a single and trifling exception it is the only one which entered the limits of the state.

The advance of the ice over the state was in a manner very different from that usually pictured by students. We have seen that it did not originate as a single cap at the north pole and advance uniformly to the south over all parts of the earth; neither did it advance with an unbroken front to its farthermost limits and then retreat. Its movement was rather a succession of advances and retreats, no single movement covering exactly the same ground as the others nor having the same extent to the southward. The different stages of advance have been called invasions and have received names suggested by the states or regions in which they had their maximum development; thus six different invasions have been made out which are called the Alberton, Kansan, Illinoisan, Iowan, Early Wisconsin and Late Wisconsin. It is the sum of these different invasions that is spoken of as the Glacial Age and the line joining the farthermost extent of each and all is spoken of as the southern limit of the ice. The criteria for distinguishing between two events so closely connected in time as two of these invasions are so obscure, involving the nice balancing of evidence furnished by the appearance of soils, the amount of erosion and the accumulation of vegetable debris that it is often beyond the power of any but the expert to determine the separation. For this reason no effort will be made to distinguish between the different stages in this book other than to note that the state was visited by at least two which have left recognizable the traces; an earlier invasion, perhaps the Iowan or even the Kansan, and the last, the Wisconsin invasion.

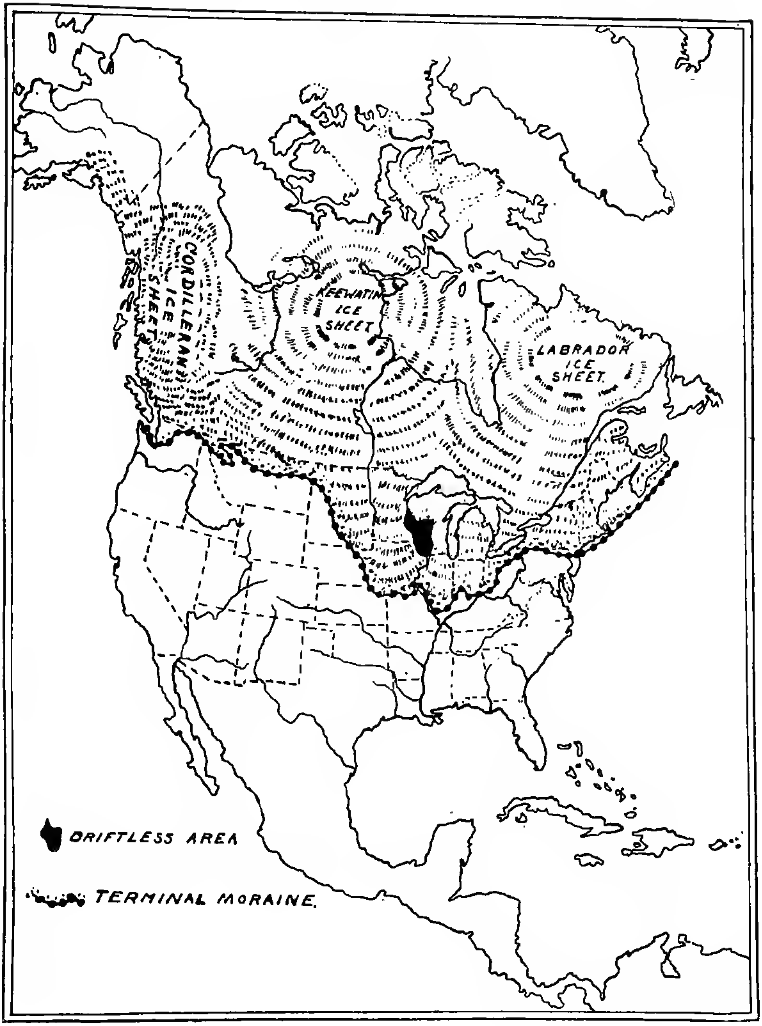


Fig. 13. Map of North America showing the position and extent of the three great ice sheets.

The forward movement of the ice over the state in the different invasions was not that of an irresistible mass with a straight unbroken front which overwhelmed everything in its path, but rather that of a plastic mass which accommodated itself to the surface and divided to pass around obstacles, doing its work of erosion in the softer rocks and leaving the harder comparatively untouched. In order to understand the form taken by the ice the structure and building of the state must be kept clearly in mind; as shown in the first two chapters, it is essentially a core of hard, crystalline rocks, which form today the highest portion of the state, flanked by successive layers of alternately harder and softer rocks, which are so tilted that they outcrop on the surface in successive parallel ridges. Already before the glacial age, the softer layers had been excavated by the rivers into lowlands and the harder layers stood up as cuesta ridges.

Both the earlier and the later ice sheets were divided into lobes by the irregularities of the ground over which they passed, but the record of the first sheet is much obscured by the deposits from the last one, which passed over much the same territory.

So far as can be made out the history of the two sheets is somewhat similar. The ice of the first invasion advancing in a generally southwest direction from the point of its origin southeast of Hudson's Bay, encountered the highlands of hard, igneous rock which form the main portion of northern Wisconsin and the upper peninsula of Michigan and at the same time entered the two great valleys which are now the beds of Lakes Michigan and Superior. As the advancing ice met the barrier of hard rocks, which it could not easily surmount nor remove readily by erosion, it was split and deflected down the convenient valleys in two great diverging lobes. The western one passed almost directly west through the basin of Lake Superior, probably giving it much of its present shape in its passage, and emerging from the western end turned southwest again, continuing in that direction until it reached far south of the present southern line of the state. The eastern portion of the divided mass continued almost directly south in the basin of Lake Michigan and when well south of the state spread out to the west until the edges of the two lobes met in the vicinity of Dubuque. During some portion of the invasion the ice succeeded in passing the highlands to the north and advanced as a short lobe over the central portion of the state as far south as Grand Rapids, approximately.

The ice of the Wisconsin sheet has left a much clearer record in the form of striations on the rocks, moraines and altered drainage lines. Advancing from the northeast the ice was divided by the same elevated region of hard rocks that divided the ice of the

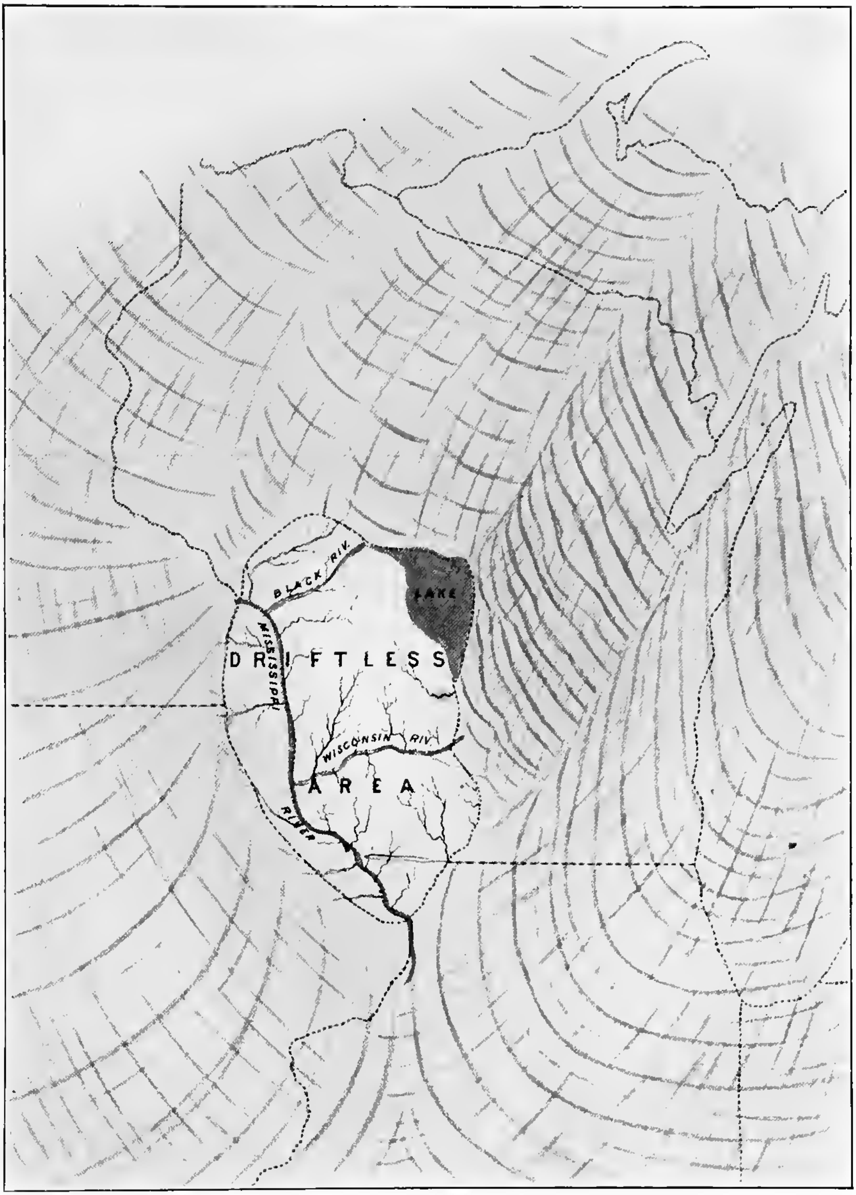


Fig. 14. Map showing the probable extent of the lobes of ice during the earlier ice invasion in Wisconsin. From the Geological Survey of Wisconsin.

earlier invasion and split into a mass which passed down the Michigan trough and one which headed westward in the Superior trough. These separate masses probably found the guiding lake basins much deeper than did the first ice, for there is no doubt that though the ice felt the guidance of the preglacial topography it shaped and molded the hills and valleys as it passed.

The large lobe that moved southward in the valley of Lake Michigan was again subdivided into smaller lobes; a larger which continued straight south and is known as the Michigan lobe, and a smaller which moved somewhat to the southwest and is known as the Green Bay lobe. A comparison of figures 8 and 15 will show that the ice of these two lobes extended down two preglacial lowlands, the Michigan lowland on the east and the Green Bay lowland on the west, and that they were divided on the north by the hard rocks of the Niagara cuesta, which projects out between Green Bay and Lake Michigan as the Door peninsula and can be traced farther north in Washington Island, Rock Island, Great Gull Island and a ridge which continues beneath the water and is revealed only by soundings.

A small lobe extends from the western side of the Michigan lobe, near the southern border of the state; it is known as the Delavan lobe from its relation to the lake of that name.

The ice in the trough of Lake Superior spread to west as in the earlier invasion, but the movement of the ice was so great that part of it was forced up the north slope of the highlands and down the other side; as it left the valley of Lake Superior it encountered the hard rocks of the Keweenawan peninsula, which divided it into two parts, just as the Door peninsula divided the Michigan lobe, the part to the east extended only a short distance to the south, invading the region which is now about the headwaters of the Chippewa river and has so been called the Chippewa lobe. The western portion extended out of the western end of the Superior trough and turned southward as the Superior lobe; it covered portions of Minnesota, Iowa and Illinois, as well as Wisconsin. As in the case of the first invasion, the Michigan and Superior lobes passed around the southern end of the state, and the middle, Chippewa, lobe did not reach far south of Wausau, so that the southwestern corner of the state has never been touched by the ice, though it is well within the limits of the glaciated portion of the United States; this is the celebrated Driftless Area of Wisconsin.

Another lobe of glacial ice just touched the borders of the state on the west, in the vicinity of St. Croix Falls, but this one was very different in origin from those which covered most of the state, for it had its birth in the great Keewatin sheet, which

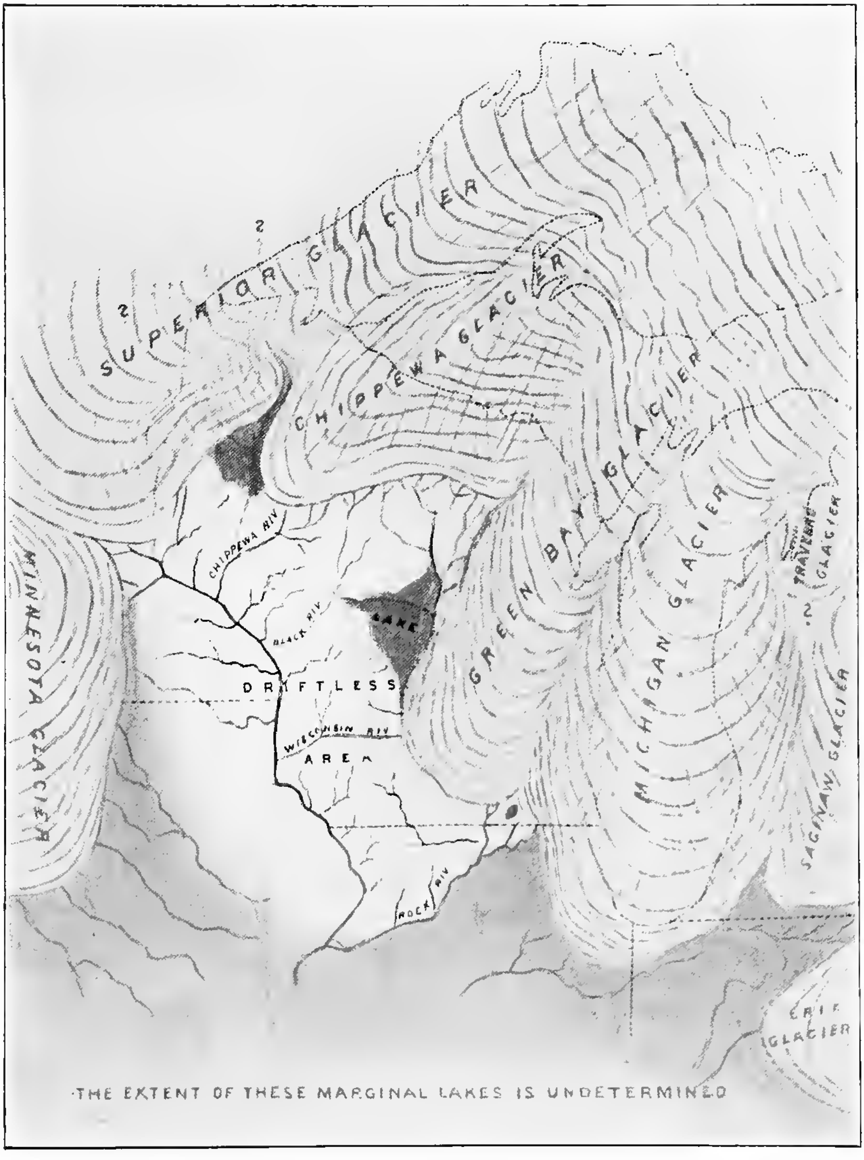


Fig. 15. Map showing the probable extent of the lobes during the last invasion of the ice in Wisconsin. From the Geological Survey Wisconsin.

developed west of Hudson's Bay and advancing to the south covered the state of Minnesota, North Dakota and South Dakota. The portion of this sheet, which advanced across Minnesota to the border of Wisconsin, is sometimes called the Minnesota lobe and sometimes the Red River lobe. This lobe of the western ice sheet and the Superior lobe of the eastern sheet met on the line between the states of Wisconsin and Minnesota and have left their records in mingled confusion. It is probable that there was an alternate advance and retreat of each lobe over the same territory, but the western glacier seems to have advanced over the region around St. Croix Falls later than the Superior lobe, and has left its deposit upon the surface. The discussion of the movements of these two lobes is given in the description of the St. Croix region.

The classification and discussion of glacial deposits has already taxed the capacity of bulky volumes and no attempt can be made in this book to do more than attempt to indicate in a very broad way the outlines of the subject. The reader who is interested in the subject is referred to the special works upon the subject (Chamberlin and Salisbury, Geology; Wright, Ice Age in North America; Dana, Manual of Geology).

Deposits from ice differ from those of water in one important character, they are never sorted or stratified; the ice carries its load as a wagon does, without regard to the weight or size of the individual parts, while the water takes into consideration the most minute differences in weight, laying down the heaviest first and carrying the lightest farthermost, so that its deposits may be perfectly sorted or stratified. Ice deposits are unstratified or unsorted; water deposits are stratified or sorted; these are dicta of the first value to the student of glaciology. But the student must not forget that the loose, unstratified glacial deposits were seized upon by the waters from the melting glaciers and rearranged and sorted in considerable measure, so that it is a most common thing to find deposits that are recognizably glacial in origin arranged in layers. It is necessary, then, to recognize stratified glacial material and unstratified glacial material; the first lying undisturbed where it was laid by the ice, the other occupying some new position, to which it has been transferred by the agency of water. In general the glacial material transported from another region and spread upon the surface of the ground is called Till or Boulder Clay.

The unstratified deposits are known as Moraines. There are two kinds in particular, the Ground Moraine and the Terminal

moraine.* The ground moraine is the material which was carried on the surface of the glacier, frozen in its substance or dragged beneath it, and which when the ice melted away remained spread upon the land in a more or less even layer, sometimes very thin and sometimes reaching several hundred feet in thickness. It is the ground moraine which forms the surface soil of the states covered by the glaciers; practically all that portion of the United States north and east of the Ohio and Missouri rivers. It covers all of Wisconsin except the driftless area.

The terminal moraine is the accumulation of material in front of the advancing ice and its position marks the foremost point of advance of the ice.. It may accumulate by material being pushed ahead of the ice, as a board pushed ahead in the dusty road and then withdrawn would leave a ridge marking its most advanced position, or it may accumulate by the ice carrying material forward on its surface and in its interior and leaving it

Front of the Great Terminal Moraine near Whitewater
From Photograph by Geological Survey of Wisconsin.

as it melts away. If the rate of forward advance and the rate of melting are about the same the deposition of material would take place at one point and a ridge marking the stationary position of the ice would be built up. Terminal moraines of the first kind are called Shove moraines; those of the second kind are called Dump moraines.

Another form of unstratified glacial material is the Drumlin. Drumlins are hills of the same material as the ground moraine and were formed at the same time as the ground moraine by

*Lateral and medial moraines are accumulations on the surface of glaciers in mountain valleys, from the valley sides. Such accumulations could not take place on the surface of ice which covered large areas.

deposition or carved from it by subsequent movements of the ice. Glaciologists are not in unison in their opinion of the origin of the drumlins, some believing that they are essentially deposits from the bottom of the ice which have been shaped by the movement of the ice, others believing that they have been carved by the ice from a uniform layer of the ground moraine in a second passage of the ice over the same region.

Drumlins are characterized by being composed of unstratified glacial material and by the form, which is that of the inverted bowl of a spoon or of half an egg. The elongate oval form thus described may become very long, as in the drumlins of central New York, or they may be nearly round; the long axis of the drumlin is always in the direction of the ice movement and the steep end is in the direction from which the ice came; they are thus valuable features of the landscape in determining the general ice movement of a region. The district around Sun Prairie and Watertown is celebrated the world over for the number and perfection of the drumlins.

Lateral View of a Drumlin in Southeastern Wisconsin
From Bull. 273, U. S. Geological Survey.

Stratified drift deposits are less simple than the unstratified; there are many kinds of such deposits recognized, but three are especially important in the state, the Kame or Esker, the Overwash plain or Apron, and the Deposits on Lake Bottoms. The kame or esker is a mass of sorted, rather than stratified, drift, for the materials of like kind are roughly accumulated in layers or lenses, but are rarely horizontal or traceable for any considerable distance. They are supposed to be accumulations gathered in very temporary lakes or streams located either upon the ice or on the surface of the earth, but confined by ice walls. As the streams overloaded with debris ran through the valley in the ice they built up their bottoms by depositing sand bars, gravel beds and

mud banks, just as do the streams of the present; when the ice walls melted away the released waters ran in new channels and the built up bottom appeared on the surface as elongate, irregular hillocks, not unlike a railroad embankment; these are called Serpent Kames or Eskers. Where the material was accumulated in a lake in the ice or confined in toto or in part by ice walls, the melting away of the walls caused the bottom deposits to appear as a hill more or less rounded in outline, dependent upon the shape of the original lake; such deposits are a very common feature of any glacial landscape.

A

B

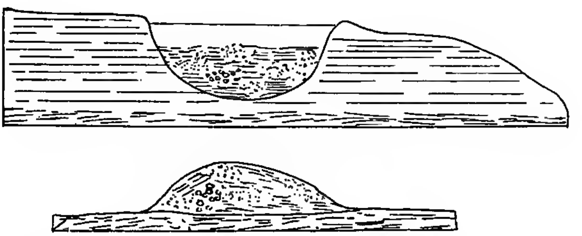


Fig. 16. Diagram showing the formation of a kame. a, The lake in an ice basin with accumulations of material in its bottom; b, The ice walls melted and the accumulations become a heap of irregularly stratified drift on the surface.

The overwash plains or aprons are formed by depositions from great sheet floods loaded with sand and gravel which spread widely over the surface and left flat areas of irregularly sorted material. When the ice had so far retreated that its front was some distance within the terminal moraine the water resulting from the continued melting of the ice front was unable to escape because it was held back by the wall of the moraine; this resulted in the formation of a series of lakes along the edge of the ice which have been called marginal lakes. When the water in the marginal lake had risen to the top of the morainal wall it rushed over as a flood, which not infrequently released the confined waters in a short time by cutting down the barrier and the material of the moraine and that accumulated on the bottom of the marginal lake during its short life was spread out in front of the moraine. Sometimes such temporary lakes were formed between the ice and the moraine, during the retreat of the ice, and floods resulting from the breaking down of the dams which held the lake caused the deposits in the lake to be spread out fan wise;

such are the sandy barrens of the northwestern portion of the state.

The deposits in lake bottoms are the most orderly of all the

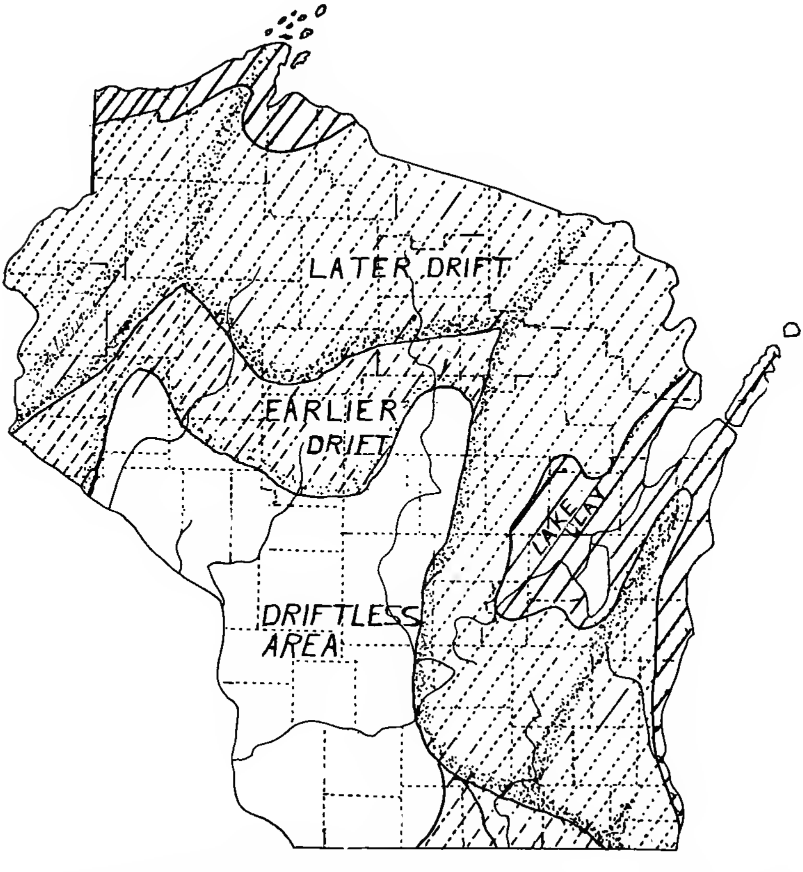


Fig. 17. Map showing the regions of Earlier and Later Drift, the Driftless Area and the deposits of Lake Clays. Compare with figure 15.

stratified drift deposits. The disturbance of the drainage lines caused by the deposition of the ground moraine and the alteration of the river channels caused the formation of an enormous

number of small lakes all over the northern and eastern portion of the state. Of course the bodies of quiet water became the seat of much deposition from all the small streams which entered them; in the course of time the basins of many of the small lakes became filled with glacial material or were drained from one cause or another, so that the orderly arrangement of the drift is easily seen. In the eastern portion of the state, where the land was covered by the waters of Lake Michigan, which stood at a very much higher level than now, the deposits of stratified drift are more apparent almost than the unstratified. Many of the glacial lakes formed as described remain still undrained and form one of the most important elements of the wonderful scenic beauty of the state.

The terminal moraine in Wisconsin is quite generally referred to as the Kettle Moraine. As would be expected from its origin, the topography is rough and irregular in the extreme; sharp, steep-sided hills alternate with deep, steep-sided holes which have no outlet and may contain ponds or swamps or be entirely dry. There is no regular arrangement in lines or otherwise of the hills and valleys and the drainage is very imperfect; every feature tells of the violent origin. The deep, steep-sided holes appeared to the first describers to resemble the large kettles used in the early days in making lye and soap, and so they were referred to as the "Potash kettles" or "kettles" and the name gradually spread to the whole ridge.

The moraine enters the state from Illinois in Kenosha county, not far from the lake shore, and extends slightly west of north to the vicinity of Burlington, where it turns sharply to the southwest, marking the position of the division of the Michigan glacial lobe called the Delavan lobe; completing a small semicircle in Walworth county around Lakes Geneva and Delavan, which marks the extent of the Delavan lobe, the moraine of the Michigan lobe joins that of the Green Bay lobe just north of the village of Richmond, Walworth county, a few miles south of Whitewater. From the point of union a strong ridge runs northeast across the state almost to the extremity of the Green Bay peninsula. From Richmond the Green Bay moraine runs almost straight north to a point a few miles northeast of Antigo, in Langlade county, where a sharp re-entrant angle marks the union of this moraine with that of the Chippewa lobe. As in the case of the Lake Michigan and Green Bay moraines a ridge runs back northeast from the point of union, marking where the sides of the two lobes met. The terminal moraine of the Chippewa lobe extends south and west in a great curve through Lincoln and Taylor counties until it meets the moraine of the Superior lobe in

Washburn county. Here again a re-entrant angle and a northeasterly projecting ridge marks the meeting of the sides of the two lobes. The moraine of the Superior lobe passes southwest and out of the state in the southwest corner of St. Croix county.

The origin of the Green Bay and Lake Michigan lobes has already been described and the influence of the preglacial basin of Lake Michigan and the Green Bay lowland in directing their course pointed out; but while the main motion of the lobes was to the south they were at the same time expanding in a less degree to the sides, so that the two lobes were overriding the sides of the channels which directed them. As the sides of the lobes advanced in a direction more or less at a right angle to the main motion they gathered in front of them and pushed ahead a terminal moraine in all respects identical in character with the terminal moraine at the front of the lobe; as the two lobes expanded, one to the west from the basin of Lake Michigan and one to the east from the valley of Green Bay, the two sides and the moraines ahead of the sides came together near the middle of the Green Bay peninsula and farther south to the point where the terminal moraines meet at Richmond. Because of the origin of this branch of the kettle moraine it has been called an Interlobate moraine. As shown above, interlobate moraines also mark the line of meeting of the Green Bay and Chippewa and the Chippewa and Superior lobes, but neither of the two is so well marked or preserved as the one in eastern Wisconsin.

Alden (The Delavan Lobe of the Lake Michigan Glacier, Professional Paper No. 34, U. S. Geol. Survey) has given a description of the interlobate moraine in southeastern Wisconsin:

"The interlobate kettle moraine is one of the unique features of this area. It is, as a whole, a bulky ridge, bordered on the east by the outwash deposits already described. The surface of this ridge is marked by a knob-and-kettle topography which varies greatly in detail from place to place. At one place there may be a series of gravel ridges not unlike railroad embankments, arranged nearly parallel to each other and to the trend of the moraine. Traced longitudinally for a short distance, these ridges become winding, inclosing deep, irregular depressions, with side slopes often as steep as 30° to 35°, or they may break into more or less distinct conical knobs, irregularly distributed and interset with equally abrupt round or irregular depressions. Differences in elevation of 20 to 100 feet occur within the space of a few rods. The close and irregular distribution of these features, and the variation in the heights of the knobs and ridges and in the depths of the hollows at many places combine to form a perfect wilderness of humps and hollows.

"On one side such an area may be flanked by a high, flat-topped, table-like ridge; on the other the reliefs may become less and the surface soften to one of gentle sags and swells, or there may be small inclosed basins 20 to 300 acres in extent, where the surface is gently undulating or nearly flat, affording tillable fields. The reliefs in general decrease from west to east, and there is usually a gradual change from the topography of the moraine to that of the bordering outwash terrace.

"The composition of this moraine, as shown by the numerous exposures and by the records of wells within the morainal belt, is largely very coarse gravel. One of the best exposures is that afforded by the abandoned railroad cut four miles southeast of Whitewater. The northwest or inner face of the moraine at this place has a relief of 140 to 180 feet and an angle of slope of 30° to 35° at the exposure, which shows the narrow crest of the abrupt morainal ridge and the upper half of the 60 to 70 foot section. There is little or no evidence of assortment and stratification. The material is mostly coarse gravel and bowlders, but with this is considerable buff clay. There is very much coarse material, many of the blocks containing 5 to 10 cubic feet of rock. The gravel is well waterworn, but much of the larger material shows comparatively little wear. The greater part of both of the coarse gravels and of the larger blocks is from the Galena and Trenton limestones. A few rods northwest of the point where this view was taken an exposure in the northwest slope shows similar coarse material, below which is coarse sand showing undisturbed strata dipping toward the southwest.

"A 50-foot section is afforded by the road cut through the morainal crest one mile southeast of Palmyra. Here the gravels, which range in size from a fraction of an inch to 8 inches in diameter, are generally well rounded. In the upper part of the section the gravels are stratified; lower down the structure was obscured when seen. The stratified gravels run laterally into very stony till.

"A third partial section of the moraine is that afforded by the gravel pit of the Chicago, Milwaukee and St. Paul Railway one mile west of the village of Eagle. The material ranges from clean waterworn gravel an inch in diameter to bowlders between 2 and 8 inches. There is so little of clay or of cementation that the gravels slide down readily through the full height of the section when excavated, so that whatever stratification is present is obscured in the exposure."

Alden has shown that a preglacial valley existed in Walworth county running from the northeast to the southwest, with sides

from 200 to 300 feet above the valley floor; the presence of the valley is shown by the depth of the solid rock below the surface of drift as revealed in wells and drilling. This valley is matched by another one to the west in Rock and Jefferson counties, which runs nearly north and south, paralleling the course of the Rock river as far north as Janesville and then underlying the present Lake Koshkonong. The easternmost valley is called by Alden the Preglacial Troy valley and the western the Preglacial Rock River valley. These valleys were partly filled by the drift of the first ice invasion, but the eastern one retained a sufficient depth to draw out from the Lake Michigan glacier a long tongue which reached nearly to the south line of the state and expanding laterally formed a distinct, though smaller lobe, the Delavan lobe. Alden discusses the origin of the Delavan lobe as follows:

"As the ice of the later advance of the glaciers of the Wisconsin stage invaded the borders of Wisconsin, the troughs formed by the erosion of the soft beds of the Cincinnati formation became the controlling factor in the separation and deployment of the Green Bay Glacier, and, in the southeastern counties, in the formation of the Delavan lobe of the Lake Michigan Glacier. The pre-glacial valleys seem not to have been obliterated by the earlier drift deposits.

While the Green Bay-Lake Winnebago trough was competent to give direction to the Green Bay Glacier, it was not sufficiently deep to confine the deployment of the glacier to its immediate limits. On the west the ice spread out 60 to 70 miles from the main axis of the lobe. In western Shawano county and eastern Marathon county, where the ice encroached upon the Archean highlands, the marginal deposits lie at an elevation nearly 1,000 feet higher than the bottom of Green Bay, opposite Sturgeon Bay. Farther south the ice, after ascending the gentle slope of the Galena formation, reached the southward and southwestward discharging valleys eroded in the St. Peter and Potsdam sandstones, which doubtless facilitated the advance in that direction, so that the ice extended to northern Rock county and northwestern Walworth county, where the Johnstown terminal moraine was formed.

On the east the deployment of the ice was confined to 20 to 30 miles from the axis of the lobe. This limitation was not, however, due to the escarpment formed by the west margin of the Niagara limestone and the underlying shales, since southward in southwestern Waukesha county the ice overrode the escarpment and began to descend the gentle eastward slope of the Niagara formation.

The Lake Michigan Glacier advanced southward along the lake basin, and on the west deployed laterally into the eastern counties of Wisconsin, where its west front moved 15 to 30 miles up the gentle rock slope. Where the opposing fronts of the Lake Michigan and Green Bay Glaciers met on this slope the advance ceased and the famous interlobate Kettle Range, or Kettle moraine, was formed.

In Illinois and Indiana the Valparaiso morainic system is believed to mark the limit of the advance of the Lake Michigan Glacier at this stage. The relations of certain outlying features have not been clearly determined.

In southern Waukesha and Walworth counties, Wis., before reaching the limits of its advance the west front of the Lake Michigan Glacier crossed the divide and entered the Troy valley. This valley, through Walworth county, has a breadth of 10 to 15 miles and its bottom lies 300 to 500 feet below the level of the higher parts of the rock surface on either side. To what extent this pre-glacial valley was filled with drift of the earlier ice invasions is not known, but that it offered a channel of easy flow to the ice nearing the limits of its advance on the gently rising slope of the Niagara formation is apparent from the fact that down this trough the ice advanced to the vicinity of the villages of Richmond, Darien and Walworth, a position nearly 25 miles farther west than the limit reached in Illinois. The village of Delavan, in western Walworth county, stands not far from the most southwesterly point reached by this glacial lobe, so that the name Delavan lobe is a convenient term by which to designate this part of the Lake Michigan Glacier.

Though the origin of the Delavan lobe appears to have been due in large part at least to the channel of easy flow offered by the Troy valley to the ice nearing the limit of its advance on the gently rising slope, the lobe, once initiated, was not confined to the limits of the valley, but spread southward over a more elevated tract between Elkhorn and Burlington and over the lower area to the south, in which is the Geneva valley, until its south front halted near the state line along the northern border of the composite morainal belt formed by the earlier glacial advances of the Wisconsin stage."

The original description of the Kettle moraine by Chamberlin (Vol. I Geol. Survey of Wis.) is very vivid and remains as one of the best accounts of this feature of the state that has been published. "The characteristics of the Kettle moraine are striking. It is not simply a ridge plowed up by the smooth edge of the ice, as is too apt to be the mental image of a terminal moraine, fashioned after the similitude of lateral and medial Alpine

moraines, but it consists of an irregular assemblage of drift hills and ridges, forming a belt usually several miles in width. It is probably owing to this width, and the very massiveness of its character, that it so long escaped general recognition as a moraine.

Its Superficial Aspects. The "Kettles."—The superficial aspect of the formation is that of an irregular, intricate series of drift ridges and hills of rapidly, but often very gracefully, undulating contour, consisting of rounded domes, conical peaks, winding and occasionally geniculated ridges, short, sharp spurs, mounds, knolls and hummocks, promiscuously arranged, accompanied by corresponding depressions that are even more striking in character. These depressions, which to casual observation constitute the most peculiar and obtrusive feature of the range, and gives rise to its descriptive name in Wisconsin, are variously known as "Potash kettles," "Pot holes," "Pots and kettles," "Sinks," etc. Those that have most arrested popular attention are circular in outline and symmetrical in form, not unlike the homely utensils that have given them names. But it is important to observe that the most of these depressions are not so symmetrical as to merit the application of these terms. Occasionally they approach the form of a funnel, or an inverted bell, while the more shallow ones are saucer-like hollows, and others are rudely oval, oblong, elliptical, or extended into trough-like or even winding hollows, while irregular departures from all these forms are most common. In depth these cavities vary from the merest indentation of the surface to bowls sixty feet or more deep, while in the irregular forms the descent is not infrequently one hundred feet or more. The slopes of the sides varies greatly, but in the deeper ones it very often reaches an angle or 30° or 35° with the horizon, or, in other words, is about as steep as the material will lie. In horizontal dimensions those that are popularly recognized as "kettles" seldom exceed 500 feet in diameter, but, structurally considered, they cannot be limited to this dimension, and it may be difficult to assign definite limits to them. One of the peculiarities of the ranges is the large number of small lakes, without inlet or outlet, that dot its course. Some of these are mere ponds of water at the bottom of typical kettles, and from this they graduate by imperceptible degrees into lakes of two or three miles in diameter. These are simply kettles on a large scale.

Next to the depressions the most striking feature of this singular formation is their counterpart in the form of hills and hillocks, that may not inaptly be styles inverted kettles. These

give the surface an irregularity sometimes fittingly designated "knobby drift." The trough-like, winding hollows have their correlatives in sharp, serpentine ridges. The combined effect of these elevations and depressions is to give to the surface an entirely distinctive character.

These features may be regarded, however, as subordinate elements of the main range, since these hillocks and hollows are variously distributed over its surface. They are usually most abundant upon the more abrupt face of the range, but occur in greater or less number on all sides of it, and in various situations. Not infrequently they occur distributed over comparatively level areas adjacent to the range. Sometimes the kettles prevail in the valleys, the adjacent ridges being free from them; and again, the reverse is the case, or they are promiscuously distributed over both. These facts are important in considering the question of their origin.

Composite Character of the Range.—The range itself is of composite character, being made up of a series of rudely parallel ridges that unite, interlock, separate, appear and disappear in an eccentric and intricate manner. Several of these subordinate ridges are often clearly discernible. It is usually between the component ridges and occupying depressions evidently caused by their divergence that most of the larger lakes associated with the range are found. Ridges running across the trend of the range, as well as transverse spurs extending out from it, are not uncommon features. The component ridges are themselves exceedingly irregular in height and breadth, being often much broken and interrupted.

The united effect of all the foregoing features is to give the formation a strikingly irregular and complicated aspect.

The passage of the ice of the last invasion obliterated in large measure the work of the earlier invasions wherever it crossed the same region, so that the moraines and other deposits of the first ice sheet are not recognizable in the region covered by the deposits of the last sheet, i. e., in that part of the state north and east of the terminal moraine. In the central portion of the state, however, there is a considerable region between the Kettle moraine on the north and the driftless area on the south which was covered by the ice of the earlier sheet alone (fig. 17); this region presents a most interesting series of topographic features intermediate between those of the recent glaciation so prominent within the Kettle moraine and those of the unglaciated surface of the driftless area. Occurring perhaps thousands of years before the last invasion and subjected to the degradation of the

interglacial time as well as postglacial the surface is in a much more advanced stage of denudation of the glacial deposits, many have been completely removed and others have been so greatly modified that they are recognizable only with difficulty. Alden says of the region to the south:

"So far as the writer's investigations have extended, there is little or no decisive evidence of the exact age of the pre-Wisconsin drift of southern Wisconsin, though it appears probable from Mr. Leverett's studies in Illinois that the drift of the Illinois stage, and probably the Iowan stage, is here represented." The pre-Wisconsin drift of southern Wisconsin is of the same age as that north of the driftless area, so that the same remarks apply to the two areas.

The terminal moraine of the earliest sheet (the Iowan or earlier) runs as a line of low hills from the edge of the Kettle moraine northeast of Wausau southwest in a sharp curve as far as Clark county and then curves north into Dunn county and southwest again out of the state in Pierce county.

With regard to glacial conditions the state may be divided into three regions: 1. A region covered by the last (Wisconsin) sheet and called the region of the "later drift." 2. Regions covered by the earlier (Iowan) sheet and called the region of the "earlier drift." 3. A region not touched by the ice at all, called the "driftless area." See figure 17.

The Region of the "Later Drift."—This includes all of the state within the Kettle moraine. It exhibits all the features that might be expected in a country of deep valleys and sharp ridges which has been covered by a layer of soft material from a few feet to a few hundred feet in thickness. The rivers which were flowing in well-established channels in deep and wide valleys were forced out of their courses by the deposits from the ice and are now engaged either in working out new channels for themselves or in clearing their old channels from the accumulated sand and gravel.

Rivers that have been compelled from one reason or another to begin anew the task of cutting down their beds are spoken of as "rejuvenated" or "revived." Their valleys have all the features of youth, being sharp and steep-sided, the course of the stream is interrupted by many falls and rapids and there are lakes and swamps telling of the imperfect drainage of the land. The streams of the region having been so recently forced aside from their well-established preglacial channels, have sought independent channels to the lakes and to the Mississippi and Wisconsin rivers. The result is that the land has relatively few

smaller streams, and these flow separately in straighter course to their mouths, instead of being gathered into systems by master streams. The difference in appearance between a young country such as that of the later drift, and an old country, such as the driftless area is easily seen upon the least detailed political map; in the first there are a few streams running in rather straight course and with few branches, in the second the land is covered with a network of small streams which are gathered into systems by a main trunk, which in turn appears as a branch of a larger trunk, and the drainage is seen to be perfect.

The hills of this region are gently rounded, the valleys are steep and sharp but not deep, the native rock is hidden under the glacial material so that it only exceptionally appears on the surface, as in the cuesta ridges. The peak and pinnacle, the bluff and hill of rock are conspicuous by their absence; such hills as do occur are drumlins and eskers or low hills consisting of a core of rock, the remnant of some preglacial prominence, deeply covered by glacial soil which more or less completely masks their true nature. These last are the "veneered hills" of Chamberlin.

The Regions of "Earlier Drift."—These are two in number, a northern between the Kettle moraine and the driftless area, as described above, and a southern, in the southeastern corner of the state, lying between the driftless area, the Kettle moraine and the state line. In general the topography may be described as a compromise between the drift covered and the driftless. The morainal deposits are lower and less conspicuous, having been broken through and partly washed away by the rivers; the rivers are more gentle in slope with wider valleys and more numerous tributaries; the falls and rapids are fewer and the lakes and swamps have been filled or drained in large measure. In a word, the glacial covering is in a more advanced stage of removal than in the region of later drift.

The northern region of earlier drift is distinguished from that of the later drift by Weidman as follows:

"In a striking manner through the weathering processes, such as freezing and thawing, the percolation of the rains and ground water, and the chemical alteration of the minerals and rocks, the earlier drift formations have become more compact and consolidated and contain a larger proportion of clay and fewer boulders than the later drift. Another important dissimilarity is in the surface features of the old and new drifts, brought about by the difference in erosion of the surface of the drift by streams and rains, whereby the older deposits have been subjected to a long period of erosion and have come to long, gentle drainage slopes

and prominent river valleys, whereas the newer drift, subjected to a shorter period of erosion, is still characterized by belts of steep drift hills, bouldery 'horseback' ridges, shallow valleys, lakes, cedar swamps and depressions. The soil conditions of the old and new drifts therefore essentially differ from one another."

Collie, in his description of the physiography of the state (Physiography of Wis, Am. Bur. Geog. Bull. 1901) subdivides the southern region of earlier drift into two provinces, the Outer drift and the Middle drift, which he names with reference to their position relative to the region of later drift, which he calls the Inner drift. His description of the two provinces is as follows:

"The Outer Drift Province.—This province is roughly triangular in form. It is widest at the state line and tapers gradually until it disappears beneath the Wisconsin drift near the southern boundary of Dane county.

The base of this triangular province is about thirty miles wide and lies between the Pecatonica and Sugar rivers. The total area of the province is about 400 square miles in southern Wisconsin.

The topography of this province combines the features of both the driftless and drift areas. The drift is spread out in the form of a sheet; this sheet is not continuous, but occurs here and there in patches. The drift is not very thick, as a rule. For this reason the pre-existing topography is not greatly altered by the presence of the drift. The valleys are filled to some extent by the drift, while the upland surface frequently contains little or no drift. This fact tends to cause less relief than is found in the driftless area. There are occasional knolls and ridges of drift; they generally lack the definiteness of such accumulations in the later drift deposits, and merge gradually into the surrounding plain. There are few abrupt transitions, such as one sees in the morainal accumulations of the Wisconsin epoch. There are no such continuous ridges; there are no true eskers, kames, kettles, or drumlins, such as are seen in the later glacial accumulations. These occasional knolls of drift have some effect upon the topography, but they are not numerous enough to have a very marked influence. The drainage is quite mature in this province; the rivers do not seem to be diverted from their original courses. There are no lakes and very slight evidence of lacustrine plains.

The Middle Drift Province.—This province is confined almost wholly to Rock county. It is quadrilateral in form and covers an approximate area of 800 square miles. The drift

is thicker than in the outer province, but it is not so thick as to wholly obliterate the preglacial topography. Preglacial valleys, notably that of the Rock, are a feature of the topography. Masses of rock, belonging to preglacial topography, rise through the drift in many localities. The drift topography is much more evident than in the outer province, and there are a great many more glacial hills. They have stronger relief and a correspondingly greater effect upon the topography. Well developed morainal ridges occur; the moraine, which the author calls the Beloit moraine, is an example. This ridge extends from the west bank of the Rock at Beloit with few interruptions to the neighborhood of Evansville, where it is buried beneath the wash from the Wisconsin moraines. Associated with the Beloit moraine at several points, especially in the neighborhood of Footville, there are gravel hills, known to geologists as kames.

Within the Beloit moraine, a few miles to the east, are found a series of smooth oval hills, known to geologists as drumlins. Drumlins are common in the inner drift province, but are very rare in the middle province. The drumlins of the middle province are located chiefly about the town of Clinton. In this particular locality the hills are low and of small size, retaining, however, the characteristic drumlin outlines. The longer axis of a drumlin is parallel to the direction of ice motion, and the arrangement of the drumlin axes in this region shows that the ice moved west.

Rock river flows through the midst of the middle drift province. It is an ancient stream, which had eroded a wide and deep channel before the coming of the Pleistocene glaciers. This channel became the runway for waters coming from the melting glaciers, this being especially true during the melting of the Wisconsin glaciers. Vast quantities of sand and gravel were carried down Rock river valley at the close of the Pleistocene by the swollen streams of that time. North of Janesville this material accumulated to such an extent that the river was forced to abandon its old channel to seek a new one. At Janesville the Rock returns to its old channel, though it is filled to a large extent with the debris of glacial origin. This gravel-filled valley is a striking topographic feature—the most striking individual feature in the province. It is a great, flat, fluviatile plain, composed of sand and gravel, which extends from the inner drift province to the Illinois-Wisconsin line and beyond. This valley train is between three and four miles wide, its length in Wisconsin being twenty miles. This flat expanse of gravel is trenched by streams, and wherever this has happened a well defined terrace exists. At Beloit the terrace is thirty feet above

the river. It should be remembered that though this gravel train crosses the Iowan, it is really of Wisconsin age. Lakes do not occur in this province, but lacustrine plains and abandoned shore lines are found."

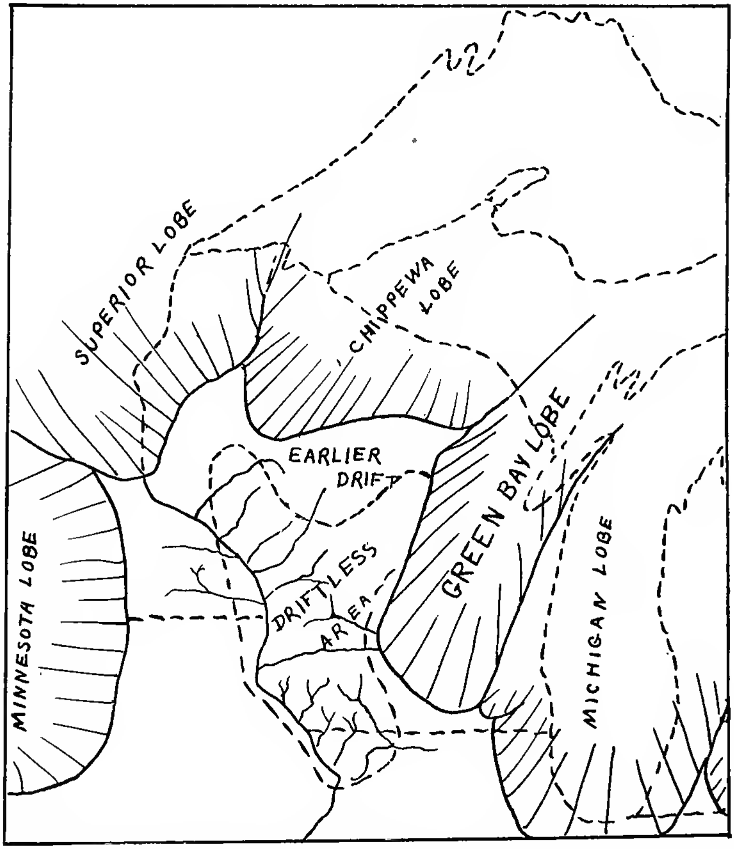


Fig. 18. Sketch showing the position of the Driftless area. Modified from Salisbury and Atwood.

The Driftless Area.—This lies in the southwestern and western parts of the state and includes narrow strips of the adjacent parts of the states of Illinois, Iowa and Minnesota. Its northern edge is indented by the convex terminal moraine of the

region of earlier drift and on either side of this it sends sharp processes to the north. Its general outline is shown in figure 18. Surrounded on all sides by glaciated country, it furnishes to the student of the state and of glaciology in general a mass of most valuable comparative material, for it shows the topography of an older land in an advanced stage of degradation immediately adjacent to regions which in the latest geological period has been covered by new deposits, now in the earliest stages of degradation. It is impossible to even list the theories that have been advanced to explain why this region was not visited by the ice, so that only one, that advanced by Chamberlin and quite generally accepted, will be reproduced here.

The driftless area lies between the great depression of the Lake Superior basin on the north and that of the Lake Michigan basin on the east, with the highlands, composed of hard, crystalline rocks, directly to the north and northeast. Lake Superior has an average depth of about 1,000 feet; its surface is about 600 feet above the level of the sea; the summit of the highlands 50 to 60 miles to the south is about 1,200 feet above the level of the lake, so there is a difference of about 2,200 feet from the bottom of the lake basin to the top of the highlands. Lake Michigan has an average depth of 900 feet and its surface is nearly on a level with that of Lake Superior, so there is a difference of about 2,100 feet from the bottom of the lake to the summit of the highlands to the west. If the lakes were drained it is seen that the highlands would constitute a very considerable elevation between them with a long slope to the south, including most of the state of Wisconsin and good parts of the neighboring states of Illinois, Iowa, Missouri and Minnesota. It is probable that the ice advancing from the northeast was split by the hard rocks of the upper peninsula of Michigan and advanced around the highland in the form of lobes which clung to the depressions of the lake basins, but in the forward movement the ice was gradually crowded up and over the obstructing highlands, and in the time of the maximum forward movement of the ice crept down the face of the southern slope in what is called the Chippewa lobe. But why, having once surmounted the barrier, did not the ice descend the southern slope as rapidly and as far as the Michigan and Superior lobes? Perhaps for two main reasons. According to Chamberlin the ice surmounted the barrier, 2,100 to 2,200 feet high, only when it was at its greatest advance, and from then on its forward movement was less rapid; moreover, the forward movement of the ice was greatly retarded as it pushed over the hills and was much slower than that of the other lobes. Again the maximum of for-

ward movement was coincident with the culmination of the Ice age, and thereafter the climate became slowly warmer; the ice, creeping down a long southern slope, was exposed to the full power of the sun and it is probable that the rate of melting was faster there than on the other lobes and faster than the rate of advance. The stronger Superior and Michigan lobes did not waste by melting so rapidly because, instead of being thinned by spreading out, they were more confined in the narrower basins and thickened by accumulation, so that they advanced more rapidly than they were destroyed by melting. It is also probable that the lobes assisted in their own perpetuation, for large masses of snow or ice, by chilling the air which blows upon them, induce an increased precipitation; so these lobes may have chilled the moisture laden air from the south or from the driftless area and caused abundant snowfalls upon their surface.

Says Chamberlin. "Divided by the Highlands, led away by the valleys, consumed by wastage where weak, self-perpetuated where strong, the fingers of the mer de glace closed around the ancient Jardin of the Upper Mississippi valley, but failed to close upon it."

Only the briefest description of the driftless area is possible here. The reader is referred to the report of Chamberlin and Salisbury (6th Ann. Rpt. U. S. G. S.) for details of the region. Their concluding picture of the contrast between this region and the rest of the state is most vivid:

"Standing on the border line, along the face of the moraine, no observer can fail to be impressed with the verity of the contrast in the phenomena presented, nor with its extreme significance. On the one side there is a perfect drainage system; on the other, drainage is incomplete and considerable areas have no external drainage at all. On the one hand is a region everywhere betraying the impress of drainage sculpture; on the other, a region which drainage sculpture is absolutely incompetent to produce. On the one hand the drainage lines are symmetrical; every least ravine fitly joins its neighbor ravine, and their confluent valley joins another of like origin, leading on and on to other unions until the whole system has gathered into the great drainage arteries of the region. Not an acre is without its appropriate portion of the drainage system, save an occasional solution pit, or an abandoned channel on the bottoms, or an inter-dune depression. On the other hand, the drainage lines are distorted into irregular and anomalous forms; the valleys are gnarled and twisted, blocked by ridges, or anon expanded into flats and marshes or lakes, or otherwise deformed in the most irregular and unsymmetrical fashion. On the one hand

are intelligibly arranged ridges, betraying the hand of nature's symmetrical sculpture; on the other, ridges bunched in the most irregular forms, setting at defiance all laws of symmetry and orderly arrangement. There is the contour-beauty of symmetry set over against the even more unique beauty of asymmetry. On the one hand are rolling hills, with smooth erosion contours or with mural faces outjutting along their steep sides; on the other, a sea of confused drift hills. On the one side is a thin mantle of residuary material; on the other a thick corrugated sheet of heterogeneous drift. On the one side is only local material, the simple result of universal terrestrial agencies; on the other, an inextricable mixture of local, semi-local, and foreign material, the extraordinary results of phenomenal causes. The one region is bowlderless, while over the other are strewn in great abundance erratics from distant regions. On the one hand the rock surface below the residuary mantle is of an irregular, rotten, half-decomposed character; on the other it is usually denuded of its decomposed material, its asperities are reduced, and its surface is polished and striated in that unique fashion which is the distinctive work of glaciers."

As the driftless area lay in the path of the drainage from the melting glaciers, it naturally received a considerable deposit of material in the form of modified drift; these deposits are called by Chamberlin and Salisbury the fringing deposits. They take the form of outwash plains, lake beds and in the rivers which rise in the drift-covered region they extend far down the course of the stream as deposits called Valley Drift. In the case of the Wisconsin and Black rivers glacial material is found in the beds and flood plain even to the mouths where the streams join the Mississippi. Typical of such river deposits are those in the valley of the Lower Wisconsin. The river crosses the Kettle moraine in the western part of Dane and Sauk counties and enters the driftless area. Its valley drift is thus described by Chamberlin and Salisbury: "In the immediate valley of the river the moraine is composed of gravelly constituents, disposed in kame-like hills and ridges, or undulating and pitted plains, showing the combined action of waste and push on the part of the glaciers and the waters. Originating from this gravelly moraine there stretches away a flood train of gravel and sand, reaching down the valley to the Mississippi, and there joining similar gravel streams from higher up, it continues down through the driftless area and beyond, though only remnants of the once continuous streams now remain. The valley drift first appears at a height of over 100 feet above the present level of the Wisconsin river, and as it stretches down the valley gradually de-

clines, so that, as it leaves the driftless area, it is barely fifty feet above the Mississippi. Near its origin coarse cobbles, bowlderets, and even occasionally bowlders are not infrequent. Farther down the material becomes finer, and, in the lower stretches, only pebbles and sand are found. The lessening coarseness of the deposit seems to show that as the glacial waters issued from the edge of the ice they were overloaded and struggling with a burden too great for their complete mastery, and, while they successfully carried the silt, sand, and even some of the finer gravel far down their courses, the heavier material in part lodged near its origin and progressively filled the channel."

This description would apply very perfectly to all the streams which rise in the drift-covered regions and flow across the driftless area. The height of the valley drift in the river valleys above the present level of the rivers indicates pretty closely the level of the rivers when they were in flood, carrying off the water from the melting glaciers. The streams, overloaded with debris in spite of their increased volume, were compelled to lay down considerable quantities of the material and so built up the valley bottom into a broad flood-plain, but as the ice finally disappeared and the rivers returned to their normal rate of flow the loose surface material was also considerably less and the rivers, though decreased in volume, were no longer overburdened with material washed into them and were able to pick up some of the material formerly laid down and begin to clear out their channels again; this resulted in a narrow and sharp trench being cut in the flood-plain and leaving on either side narrow benches of flood-plain material, the River Terraces.

The origin of river terraces is a simple matter; it may be briefly described as follows: The carrying power of a stream varies remarkably with its velocity; the law regarding this says that it varies with the sixth power of the velocity (Chamberlin and Salisbury, Geology, Vol. I., p. 110), i. e., if the velocity is doubled the carrying power is increased 64 times; if it is trebled the carrying power is increased 729 times; the carrying power diminishes at the same remarkable rate. A stream that has more material poured into it from the sides than it can carry is said to be overloaded, and is compelled to lay down some of the material in the form of sand-bars, etc. A stream may easily be overloaded in one part and not in another, as the slight change in velocity in different portions has such a great effect on the carrying power. A stream has very different velocity in different parts of the same section, for the average velocity of the sides and bottom is about one-half of that of mid-current. When a stream is in flood its velocity is greatly increased and its carrying power

enormously increased, but the flood waters of the stream extend beyond its banks and spread out over the adjacent country in a shallow sheet, and the retarding action of friction on the widely spread waters and the halting action of objects that the water meets lessens the velocity and causes a great deposition of the carried material, so that a broad, flat land is built up on the side of the streams, very appropriately called the flood-plain. If for some reason the river continues the building up of this flood-plain, the bottom of the valley may be raised considerably above its original level. If the river now changes its character so that instead of filling it begins to cut, i. e., if it is rejuvenated, p. 70, it will begin to remove the material of the flood-plain, cutting a narrow trench, and the portion of the flood-plain on either side

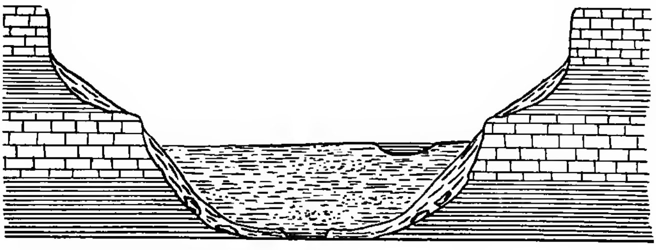


Fig. 19. Cross section of a valley partly filled with drift deposited in the form of a flood plain when the river was overloaded.

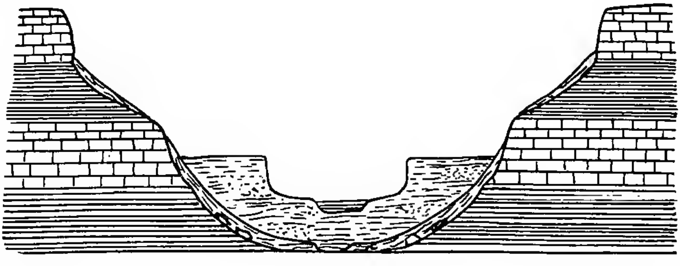


Fig. 20. Cross section of the same valley when the stream has removed a portion of the previously deposited material, leaving terraces on either side.

of the trench will form a flat bench or terrace with an even top; in a typical case there would be a terrace on each side of the

river with the tops on a level, but the river may flow more against one side than the other and completely remove one terrace while the other is still very wide and high. The river may regain its velocity and cutting power in several ways. (1) The river might be temporarily dammed so that its current would be slowed and deposition take place above the dam in the quiet water. The damming might be accomplished by any one of a number of accidents, as a landslide which would fill up the stream channel, a temporary ice dam, a lava flow across the course, the rising of the land across the stream, etc., etc. When the stream had cut through the obstruction which barred its path it would resume its normal rate of flow and the previously deposited material would be removed so that the stream would cut a channel through the material deposited in the quiet waters when the river was ponded back. (2) The stream might be overloaded in spite of its great carrying power. When the ice was passing away from the surface of the state it seems certain that there must have been a great mass of water furnished by the melting ice, and the condition, on a larger scale, was just what occurs in every plowed field in the spring when the snow melts and the frost comes out of the ground. The glacial soil was loose and unconsolidated and great quantities were carried by the surface waters into the rivers. The streams into which the surface waters finally found their way were in a state of high flood, but at the same time were given an enormous load of the loose glacial debris to carry, so great a load that it was beyond their power and much of the loose material was laid down on the bottom of the valley, filling up the bed and building up a wide and deep flood plain. The level of the flood plain not uncommonly reached far above the level occupied by the stream in preglacial times. Later, as the surface water had removed much of the immediately available material, the rivers cleared, their load was less and even though their volume was also less, they were now able to pick up some of the material which they had previously laid down and carry on again; so new channels would be formed in the deposits and the surface of the flood plain would appear on either side of the stream as a sort of shelf clinging to the sides of the valley; these are the "terraces."

This latter is probably the history of the terraced rivers of Wisconsin, both those which flow in the region covered by the drift and those which rise in the drift covered regions and flow across the driftless area.

Near Prairie du Sac the Wisconsin river has nearly completely removed the flood plain material on the south side, so that there is no terrace, and the river runs against a bluff cut in

the preglacial valley wall, but on the north side there is a terrace with its surface over 100 feet above the present level of the river. A little farther down stream the river has made much greater progress in the removal of the glacial material, but there are traces of terraces all the way to the Mississippi. The valley of the Wisconsin "is but a lesser twin of the Mississippi;" near its mouth it has a flood plain nearly three miles wide and bluffs on either side averaging 375 feet high; its tributaries below Prairie du Sac have the same character of wide valleys and bluff sides, but lack the great deposits of glacial material and the terraces, for they originate in the driftless area and were never overloaded with glacial debris.

The other streams which cross the driftless area have the same character as the Wisconsin river and show terraces proportioned to their volume. The prominent ones besides the Wisconsin are the Mississippi, the Black and the Trempealeau. The valley of the Mississippi within the limits of the driftless area has steep valley walls from 300 to 600 feet high, which are cut through at short intervals by the valleys of tributary streams; above and below the driftless area the river runs in a shallow trough through a wide, flat valley formed in a drift plain. The rock walls of the driftless area are preglacial in origin, while the shallow valleys in the drift plain are of glacial origin. There are few traces of terraces on the sides of the Mississippi; from all evidence there was originally a wide and deep flood plain formed during glacial times, but the volume of the mighty stream has cut its terraces down and swept them away with nearly all traces of the flood plains in the few years since the ice passed away.

The Black and Trempealeau both show a system of terraces originating in the same way as those of the Wisconsin, but smaller.

The Chippewa river, though not crossing the driftless area, shows a system of terraces of the greatest interest. They are in many cases higher above the level of the river than those of the Wisconsin and the valley between them is narrower, showing that the work of clearing out the valley has made much less progress. There are in most parts of the valley several terraces, one above the other, in a step-like arrangement, indicating several successive stages in the level of the river and the clearing out process. The highest terrace, showing the level of the river in glacial times, is 65 feet above the level of the river at Chippewa Falls, 80 at Badger Mills, 130 at Eau Claire below the falls, 90 at Meridian, and 63 at Durand.

The terraces of the St. Croix will be described in the discussion of the St. Croix Dells.

The valleys of the rivers which rise within the driftless area and flow into the Mississippi or Wisconsin are very different from those which rise in the drift covered area and flow across the driftless area; having never received the great volume of water from the melting of the glaciers nor the great quantity of drift material carried into the rivers by the side streams they have never built up wide flood plains and have never been compelled to trench out their valleys again in an old flood plain. The valleys are wide, with gently sloping sides varied by occasional bluffs; they are typical mature, preglacial valleys.

The sequence of events in the driftless area as given by Chamberlin is as follows:

"(1) Great stage or erosion. (2) The extension of the ice around the area and uniting below it. The deposits from this invasion form the thin deposits on the northern and southeastern borders of the area. (3) Deglaciation of the neighboring regions, so that there was a considerable erosion and growth of forest and vegetation. (4) The second glacial invasion, burying the forest growth. (5) A long period of freedom from ice with erosion and elevation of the region from 800 to 1,000 feet. (6) Last glacial invasion. (7) Alternating ice and re-erosion. (8) Formation of terraces."

CHAPTER VI.

THE SHORE LINE OF WISCONSIN.

Wisconsin terminates on the east and north at the edge of the two great lakes—Lake Michigan and Lake Superior. This has been distinctly to her great advantage, as it has permitted the development of the commerce which depends on the traffic of the great coasting steamers carrying the ore and lumber, the passenger steamers and the comparatively modern car ferries, which are building up to greater importance several of the coast towns.

The northern shore will be described first. The form of the shore of Lake Superior depends upon three things: (1) The structure and composition of the rock. (2) The glaciation. (3) Subsequent depression.

1. Composition of the Rock.—A glance at the geological map of Wisconsin (fig. 1), with its cross section, will show that the northern border of the state was formed on exactly the same plan as the southern, i. e., when the central Archean mass was an island there was laid down on its continental shelf a series of deposits which were later elevated into a coastal plain, as in the south; this coastal plain was later sunk in a great trough, the Lake Superior syncline. The only portion of the northern coastal plain which is identifiable with that of the southern coastal plain is the sandstone of the Cambrian time, which in the south forms the inner lowland. It exhibits the same character in the north as in the south except that it is somewhat harder and is stained a deep red by the presence of large quantities of iron oxide (haematite). It has the local name of "Lake Superior sandstone." The upper section of the Lake Superior sandstone is composed of light, almost white sandstones of generally soft and friable nature. The lower section is colored intensely red by iron pigment and contains various hard, compact ledges, which are valuable building stones. As Irving described it: "The prevailing color of the rock is some shade of red, from bright brick red

to a brownish red or purplish red. Pinkish, straw-colored, and even nearly pure white varieties occur, either blotching the ordinary rock in small patches or occurring in layers from an inch to two or three feet in thickness."

Chamberlin (Vol. I, Geol. Survey of Wis.) thus describes its appearance: "Lake Superior Sandstone.—The sandstones on the southern side of the Archean island (the inner lowland) are light colored, being mainly yellow or white, varying locally to pink, brown and green. They are nowhere bodily dark. An easy explanation of this is found in the fact that they were derived from the light-colored quartzose and granitic rocks of the southern face of the land. But passing around to the Lake Superior basin on the northern side of the land, where erosion preyed on the iron-bearing members of the Huronian series, the resulting beds are not only reddish brown in color, but contain a notable ingredient of iron and shaly material derived from those formations. Indeed, the deposit bears a very close external resemblance to the sandstones of the Keweenawan series. * * *"

2. Glaciation. — On its southward course the great Superior lobe of the ice overran this shore, leaving a deposit of drift from a few feet thick to as much as 300 in places; this now covers all the shore and in places meets the water in slanting bluffs, but in others has been so far removed that the sandstone below forms vertical bluffs.

3. Subsidence. — There is ample evidence that the portion of the bottom of Lake Superior adjacent to the present shore was at one time above the surface of the water and in preglacial time was sculptured by the rivers into deep valleys and isolated hills very similar in appearance to the driftless area today. Subsequently the region sank so that the land was drowned and the water ran up the river valleys and covered the lowlands, leaving only the tops of the isolated hills above the water. These appear today in Bayfield county as the Apostle islands. It is possible that the land was again elevated during the later part of preglacial time and while the ice was present, but after the ice disappeared it sank again and has remained in that condition ever since. The effect of the postglacial subsidence is described more fully below.

In the following detailed description it will be seen that each one of three experiences described above has left its trace on the shore; in places the clays of glacial time still meet the water's edge; in others the waves have removed the clay and the shore is formed by bluffs of Cambrian, Lake Superior, sandstone; in

still others, as the Apostle islands, the depression of the land has left only the tops of the higher hills above the water.

Beginning at the mouth of the Montreal river, the shore is formed by high bluffs of red sandstone reaching as much as 90 feet above the lake. The sandstones are connected with the hard rocks of Penokee-Douglas range, which form the backbone of the Keweenawan peninsula but a little farther west; at Michigan point or Little Girl point, the hard rocks retreat somewhat from the lake and the clays and sand of the glacial deposits form the shore line. A short distance off shore from the bluffs of crystalline rocks the water deepens suddenly to many fathoms. Increasing in importance westward, the clays form slanting, retreating bluffs with a beach of considerable width at their foot and beneath the water line a wide shelf covered by shallow water. At Clinton point the bluffs are from 40 to 60 feet high; west of this they are low to the mouth of Bad river.

A bluff or wave cut cliff in unconsolidated sands and clays can never present the same outline as a cliff of harder rocks. The main action of the waves is in a narrow zone at the base of the cliff, where they cut by the impact both of the water and of stones carried in the water and by rolling and grinding the boulders, pebbles and sand of the beach. A cliff of hard rock may have the base of the cliff cut away sharply and even undercut by the waves and still the rocks stand upright because of their resistance, so that sea caves, arches, isolated pillars, and vertical faces will be formed, but in a cliff of soft material as soon as the base of the cliff is cut away and the face approaches the vertical, land slides result and the slope is again restored. Such a cliff retreats much more rapidly and uniformly than a cliff in hard rock, but can never present the same picturesque features.

The zone of shallow water rapidly widens toward the west until off the Apostle islands the 20 fathom line (120 feet deep) lies twenty miles from the shore. The presence of such a wide belt of shallow water has produced a marked difference in the shore line; where the water is deep close to the land the material brought down by the rivers is swept away quickly by the waves and disappears in the depths of the lake, but where the water is shallow the deposits on the bottom of the lake soon reach to the surface, are beaten back by the waves and carried by the currents, forming bars, spits, shallows and wide deltas. Many of the rivers of this portion of the coast flow in their lower reaches through wide swamps and marshes formed in this way. This is especially well illustrated in the Bad river, described below, where the material brought down by the river has been beaten back by the waves, forming so wide a marsh and such an obstruc-

tion to the channel that the river has been diverted from its former course into Chequamegon bay and now flows into the open lake (fig. 21). West of the mouth of the Bad river the shore is sandy and swampy and the waves have built up bars and the winds have heaped up dunes along the beaches. The most prominent bar, Chequamegon point, lies across the mouth of the Chequamegon bay and acts as a most efficient breakwater, protecting the bay from the sweep of the waves and guarding the

Fig. 21. Map showing the Bayfield Peninsula, Chequamegon Bay and the Apostle Islands.

opening to the harbor of Ashland. It carries on its extreme point two lighthouses and a bell for the guidance of the lake steamers making this port. The bar is seven miles long and from 300 to 1,000 feet in width; behind the bar, in the quiet water, the shore accumulations from the rivers and wind have shallowed the water, so that it has at no place a greater depth than 18 feet except a narrow channel which leads to the docks of Ashland.

In several places the Chequamegon bar has been broken through by the waves in time of storm and these "sand cuts," as they are called, are not being repaired by the waves, but are rather increasing. This is taken as evidence that on the whole

the shore is gradually sinking and the water becoming deeper. The surface of the bar is largely built up of wind blown sands which accumulated as soon as the waters had raised the ridge above the level of the lake. The wind frequently erodes the sand forming deep, funnel-shaped cavities, which are enlarged on the opposite side, in the direction of the prevailing winds across the bar, until a wide wind cut gap is formed through which the water easily breaks in some time of storm.

Chequamegon bay and its protecting bar has a most interesting history. As shown above, it occupies a natural depression between the Douglas and Penokee ridges, which unite to the south. The depression was filled by Cambrian sandstones, but during the long ages of degradation which succeeded the final disappearance of the sea in Devonian time the sandstone was vary largely cleared out again. With the advent of the glaciers the bay was pretty largely filled by drift and assumed somewhere near its present form and size. The present condition is largely due to the long bar extending across its mouth and behind which are gathering the deposits of the rivers which flow into the bay.

Chequamegon point is a typical wave and current built lake spit. When a large body of water, as the ocean or the Great Lakes, or even some of the smaller lakes, are visited by winds prevailing from one direction currents are set up in the water which move in a direction generally parallel to the motion of the wind but governed in considerable measure by the character of the bottom and the contour of the shore line. These currents move a very considerable quantity of sand from one part of the shore to another, scouring it out where the current is uninterrupted and has a strong sweep and depositing it where the waters

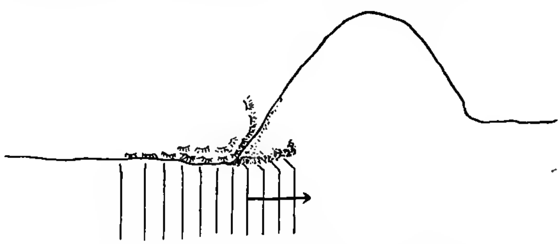


Fig. 22. Diagram illustrating the building of a spit. The waves moving past the headland are indicated by the lines.

are quieter. When the current sweeps past a prominent headland it is apt to remove a considerable quantity of material, because the water is deeper and unobstructed and the land extends

out into the full sweep of the water. As the current sweeps past the prominence and across the mouth of the bay or inlet which succeeds, the current has a tendency to widen out towards the quieter waters, but in coming in contact with the quieter waters its velocity is checked and it lays down some of the material it carries, for the same laws govern the carrying power of a current in a lake or ocean as govern the carrying power of a river or stream, and the most important of these is the relation of the load to the velocity (p. 78). The process is illustrated in figure 22.

Waves form bars off shore across the mouths of rivers and bays in a rather different manner. If the bottom is sandy or cumbered with loose debris brought down by the rivers and is shallow for a considerable distance out from the shore, so that the material at the bottom is within the shallow zone which feels the disturbance of the waves, the wave currents pick up the material and carry it toward the shore in their inward rush, but as they approach the shore and feel the retarding action of the shallowing water the load is in part deposited and a line of bars is

Fig. 23. Diagrams illustrating the stages in the building of Chequamegon point. 1. The Original bay; the dotted lines indicate the outlines of the present bay. 2. Oak Point bar stage; Bad River bar forming; Oak Point bar complete. 3. Union of Oak Point and Bad River bars. 4. Beginning of Chequamegon Point; the marsh is forming behind the bar. 5. Present condition; the bars complete. From Collie.

built up at a point which is determined by several factors, as the strength of the waves and currents, the amount of loose debris and so forth.

Chequamegon bar owes its existence to both of these processes. Collie (Physiograph of Wis., Bull. Am. Bur. Geog., Vol. II., 1901) has given an account of the history of the building of the bar, which is here followed and illustrated by figures taken from his article.

The first stage was the formation of Oak bar across the center of the bay by the building action of the waves. The land was slowly rising, probably just after the lake had assumed its present level, and this progressive shallowing of the water, together with the large amount of glacial debris available, permitted the waves to build up a bar opposite the center of the bay. The bar was originally five miles long, "averaging 100 rods in width, and is made up of several parallel ridges, the oldest of which lie inside the bar toward the mainland." The second stage was the development of a spit out from the mainland which finally reached the bar and connected it with the shore; this was built by the action of currents parallel to the shore. "It is a single ridge, the upper portion of which is composed of wind-blown sands." The third stage was the continuation of the development of the spit out beyond the Oak Point bar by the currents parallel to the shore. This portion is called Long Island at times; it "consists of two portions, which were formed probably at different times. One portion, the west end, is a broad bar made up of several parallel ridges. The other portion, the eastern, is a single narrow ridge, which joins the expanded western end of Oak Point bar."

The Apostle Islands, so called from their number, twenty-four, are, even to the most casual observer, evidently detached portions of the mainland, broken fragments of the once more extensive Bayfield Peninsula. They are essentially flat tables of the red Lake Superior sandstone covered in part by glacial drift and with the edges cut into bluffs by the waves.

The surface of the interior of the adjacent mainland is very ragged, being cut up by preglacial valleys in the hard Archean rocks, but the shore is flatter because the softer sandstone has yielded more readily to the erosion of the glaciers, and the preglacial valleys are filled with drift. As mentioned above, the Apostle Islands were in preglacial times a portion of the mainland which was cut up by stream valleys into isolated blocks, and as the land sank the deep valleys were filled by the waters of the lake and the blocks became islands. This subsidence is also shown in the condition of the mouths of the rivers, the val-

leys of which are "drowned," and in the destruction of the previously formed bars. A drowned river is one which, after having worked out a definite valley on a land adjacent to the coast, has its valley partly filled by the sinking of the land and the incursion of the water. The process can be readily understood by comparing any of the rivers of the Atlantic coast south of North Carolina with the condition of the rivers of North Carolina and the Chesapeake and Delaware bays. The rivers to the south are

The Sphinx, Showing Lake Bluff on the Superior Shore cut in Fairly Hard Sandstone

flowing over a flat plain of soft material and have worked out relatively crooked courses with wide valleys and many tributaries. If it is imagined that the land in this region sinks a few feet it will be seen how the sea water would run back up the valleys of the main stream and of the tributaries, filling them to the same level and forming the crooked, many branched bays of the North Carolina and Maryland coast. Such a condition of the river valley is good evidence of a local or general sinking of the land.

An elevation of 50 feet in the surface of the lake would cut off Bark, Siskiwit and Detour points, forming new islands. A depression of 50 feet would connect York, Raspberry, Oak and Basswood islands, and one of 60 feet would connect Madeline Island with the main land.

From the Apostle Islands west to the mouth of the Brule river the shores are formed by bluffs of red sandstone 10 to 40 feet high. In these bluffs, as well as those of some of the islands, are cut the caverns, arches and detached pillars of curious and beautiful forms that have gained for this portion of the lake shore its reputation for beauty. The caverns in the bluffs of Oak Island have a height of fifteen feet above the water line and the floor is deep under the surface. The waves in forming the cave have cut back as much as a hundred feet in some cases, but the depth is usually much less. In some parts of the shore the caves take almost the form of corridors, several caves joining, well within the cliff, but opening by separate mouths. The excavation of the caves seems to be governed in large measure by the character of the sandstone; where the sandstone contains much clay it is easily cut out, but where the siliceous cement is abundant it is more resistant. No portion of the Wisconsin shore of Lake Superior can be called grand or imposing, for its bluffs never reach a height greater than sixty feet above the lake, but much of it presents a unique beauty in the coloration of the rock and the peculiarity of the wave sculpture.

Beyond the region of sandstone the shores are again formed by clay, even to the western limit of the state.

The harbor of Superior and Duluth at the extremity of the lake is formed by a great, wave-built bar of sand thrown up across the mouth of the St. Louis river. This bar is broken by a narrow entrance near the Wisconsin shore, called the Wisconsin entry or the Superior entry; originally the channel across the bar was narrow and winding with not over 11 feet of water and sometimes less than 9, but harbor improvements have deepened the channel to 23 feet and straightened the course. The portion of the bar connected with the Wisconsin shore is called Wisconsin point and that next the Minnesota shore is called Minnesota point. The latter has been pierced by a ship canal near the Minnesota shore by the enterprise of the citizens of Duluth. Within the bar a channel leads into an expansion of the waters of the St. Louis river called the inner harbor.

The shores of Wisconsin along the edges of Lake Michigan are formed almost entirely by glacial deposits. The upper surface of the Niagara limestone which comes down to the water's edge is covered in only one or two places by the Devonian lime-

stone and it disappears under the surface of the water at a low angle, but it is so deeply covered by the glacial clays and sands that only occasionally is it exposed by the action of the waves, as toward the extremity of the Green Bay peninsula; on the eastern side of Green Bay the limestone appears in prominent

Lake Bluff in Glacial Material at Racine. Photo by Alden, U. S. Geological Survey.

bluffs as described on an earlier page. Along the greater portion of the shore the layer of glacial material is so deep that the waves are still engaged in removing it and the cliffs are cut in the boulder clay and the modified drift overlying it. It would be impossible, even in an extended work, to describe the various layers of glacial material in the bluffs; suffice it to say that in general the lower portion of the bluffs are formed by the unmodified boulder clay, which lies directly upon the Niagara limestone, and the upper portion by various layers deposited from waves and currents, or in the quieter water farther from shore when the surface of the lake was much higher than now. These overlying deposits are the so called beach deposits and the red clay.

The boulder clay is much harder than the modified drift above and frequently stands up on the lake shore as nearly vertical face several feet in height. The boulder clay was formed under the ice and in the movement of the glaciers was subjected to a rubbing and mixing movement similar to that employed in the brick yards, but on a much more extensive scale; moreover, it was subjected to the enormous weight of the ice above. The tempering by the kneading action of the ice and the compression due to the weight above has compacted this material so firmly that it is very resistant, yielding to the action of a pick or plow only when wielded or dragged with considerable force. The greater hardness has won for it the name of "hard pan," and it lies under the glacial soil over a considerable portion of the state; having been kneaded so thoroughly by the movement of the ice, it is so compact as to be practically impervious to water, and it frequently forms the bottom layer which determines the location of springs or wells.

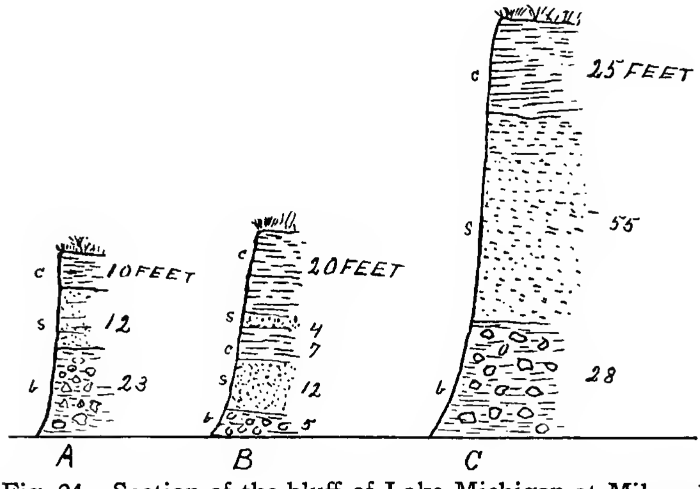


Fig. 24. Section of the bluff of Lake Michigan at Milwaukee. a and b, at Milwaukee; c, at Whitefish Bay; c, red clay; s, sand; b, boulder clay.

The deposits of modified drift in the bluffs were of varying thickness when laid down, dependent upon the amount of material that was swept in from the land, and they have subsequently suffered much erosion by the action of rivers and rain

wash, so that frequently a layer present in one place is absent in another, nor is it to be supposed that there was ever a series of continuous layers the whole length of the Michigan shore; in one place a large sized river has swept in a series of delta deposits that are totally absent in another, and a region of deep water in one part receiving deposits of red clay would, a few miles farther along the shore, be turned into shallow water, forming beach deposits. There is, then, no possibility of there having ever been a uniform series of deposits of glacial material traceable along the whole length of the shore. The accompanying diagrams (fig. 24), taken from Vol. II of the Geological Survey of Wisconsin, give an idea of the varying character of the deposits and of the height of the bluff.

Near the south line of the state the shores are low, not over 25 feet in height, and are formed of the coarse sands and gravels which are taken as typical of an ancient beach. Between Kenosha and Racine the bluff rises and shows a considerable thickness of boulder clay at the bottom; in its elevation the bluff reaches and retains a height of from 75 to 125 feet as far north as Port Washington. A few miles north of Port Washington the bluff is low again and continues so to Sheboygan; from Sheboygan to Manitowoc the shores are bluffy and from there on they are low to the extremity of the peninsula with the exception of the vicinity of Kewaunee, where it reaches a height of 75 feet. The unmodified boulder clay appears at the foot of the bluff only between Kenosha and Port Washington.

In no place do the bluffs present a perpendicular face, for, as explained above, the soft material is unable to support itself at a very steep angle, and as soon as the waves, by cutting at the foot have produced a nearly vertical face repeated landslides restore the original slope. The rapid retreat of the bluff due to repeated landslides is a source of much annoyance to cities which are located on the lake shore and extraordinary precautions are necessary to prevent injury to park and other frontage from this cause. In the vicinity of Milwaukee the edge of the bluff is retreating at the rate of from one to three feet per year.

Rounding the rocky point of the northern extremity of the Green Bay peninsula the character of the shore changes; the Niagara limestone appears in the shore and becomes higher towards the head of the bay until at Chambers Island it takes on the character of a bluff which continues to grow in height until at the south end it attains a height of from 250 to 300 feet. The western shore of Green Bay is low with a very gradual slope upward toward the west; it is formed of glacial clay and covered by swamps and evergreen trees.

All along the Michigan shore there are wave-cut terraces telling of the former higher level of the lake. A wave-cut terrace is very different in origin from a river terrace. The formation of the latter has been explained already (p. 78); the wave-cut terrace is formed somewhat as follows: A wave is at best a very shallow phenomenon, the disturbance is confined to the upper layers of the water and diminishes very rapidly downward. Thus the cutting action of the wave and its transporting action are confined to shallow waters. When a wave breaks on the shore at the foot of a cliff it undercuts the cliff by the actual impact both of the water and of the pebbles and stones carried in the water and by wearing away the rock by dragging the stones back and forth over them. The material thus loosened by the wave is carried out as far as the retreating water maintains enough motion to act as a current. Wave action thus tends to produce a level region a short distance below the surface both by cutting and by building up. See figure 25. When the level

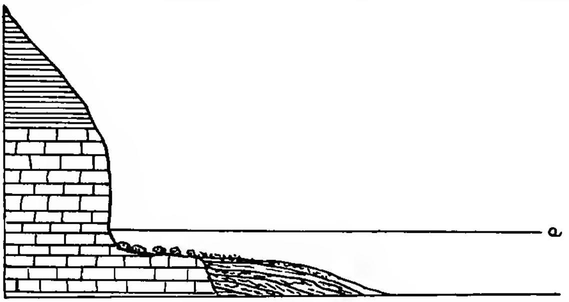


Fig. 25. Section of a wave-formed terrace in fairly hard material, showing the area of shallow water formed partly by cutting and partly by filling. a, water level.

of the water is lowered it is evident that such wave-built levels will form terraces indicating the old shore line and approximately the former level.

All along the Michigan shore are remnants of terraces indicating the former higher level of the lake, but in many places they have been destroyed by erosion since their formation. A very good example exists in Lake Park, Milwaukee, where a rather wide shelf about ten feet above the present level of the lake ends abruptly at the foot of a bluff nearly eighty feet high. This terrace is traceable for several miles north of Milwaukee. At Port Washington and Sheboygan the terrace is again visible;

from Algoma to Sturgeon Bay the terrace is traceable, and it appears at intervals on the east shore of Green Bay but not on the low west shore. On some portions of the shore there are more than one such terraces, indicating the occupation of successive levels by the lake.

In the closing stages of the glacial time the general shape of the basins of the Great Lakes was probably very much as now, but the outline of the lakes was very different, for they stood at a much higher level. With the passage of the ice

Wave Cut Terrace at Lake Park, Milwaukee

from the land by melting there was an over-abundance of water, which could not pass off to the north through the natural drainage of the St. Lawrence system, for the northern outlet of this channel remained dammed by ice long after the southern portion was free. In consequence of this the waters in the lake basins rose until they overtopped the barriers to the south and found channels which would carry their waters away to the south. The record of the former higher levels and the outlets have been very plainly left in the abandoned beaches and outlet channels.

Lake Ontario drained to the south through the valley of the Mohawk and Hudson; Lake Erie through the Maumee and Wabash to the Ohio and the Mississippi; Lake Michigan through the Chicago river to the Ohio and Mississippi, and perhaps at another time, in part at least, through the Fox and Wisconsin to the Mississippi. Lake Superior, at one stage, drained through the Bois Brule and the St. Croix to the Mississippi; at another stage it probably had its outlet to the north, entering Hudson's Bay, for Tayler found terraces and beaches from Duluth to Sault Ste. Marie from 512 to 588 feet above the present level of the lake.

The former extent of the lakes over Wisconsin is shown in the map, figure 17. Different names have been given to the lakes at the time of their greatest extension; thus Lake Michigan at the time it flowed down to the Mississippi through the Chicago river is called the Lake Chicago. Lake Superior at the stage of outlet through the Bois Brule and St. Croix is called the Lake West Superior or Lake Duluth.

Upham (Am. Geol., Vol. 32) has recently gathered evidence to show that the waters covering the region of Green Bay were temporarily separated from those of Lake Chicago and formed a goodly sized lake which emptied through the upper Fox river into the Wisconsin and Mississippi across the site of the town of Portage. Later the waters of the two lakes may have mingled and had a temporary outflow through the Fox and Wisconsin. From the Fox river the ascent to the top of the divide at Portage is only ten feet and the descent to the Wisconsin on the other side is only five; the distance between the two rivers at this point is only one and a half miles. In times of high water in the Wisconsin the floods of especial height pass some of their waters over the divide into the Fox and finally into Lake Michigan. Also, the water from the Wisconsin in time of high flood escapes into Neenah creek, six to seven miles northwest of Portage, and after a course of about two miles reaches the Fox. Upham says of the region:—

"Between the former sites of Fort Winnebago, close east of the Fox river, and the Indian agency, close west of the river, at the distance of about two miles from the Wisconsin, a channel was eroded in the drift by the outflow from the glacial lake of the Fox valley to a depth of 35 to 40 feet, with a width of about 1,000 feet, along the distance of a quarter of a mile. The original surface there was about 30 feet above the surface of the Wisconsin river at Portage, and this channel could not have been due to the erosion by the present Fox river, which runs through it, nor by any discharge from the floods of the Wisconsin, which in this part has a range of about 10 feet from its lowest to its highest stage.

Thence the Fox river has a descent of a few feet along its course for five miles northward. In the northern two-thirds of this distance it expands to form Menominee and Buffalo lakes, six to nine feet deep and about a half a mile wide, having together a length of fifteen miles. They are thus very shallow, and are filled in summer with abundant growth of wild rice. This part of the upper Fox evidently occupies the ancient eroded channel of a larger river, which flowed in the opposite direction, being tributary to the Wisconsin valley. * * * In the city of Portage are also found evidences of this valley. The northwestern and principal part of the town is 30 to 50 feet above the river, but the southeastern part is on the low alluvial tract of the portage, subject to occasional overflow by the river floods, which thence run north and are tributary to Lake Michigan. For a mile through the town its upper portion is terminated against the lowland by an eroded bank or low bluff, cut by the outlet of the glacial Lake Nicolet. On the lowland near the foot of the bluff, a canal connects the Wisconsin with the Fox."

This lake, called by Upham the Glacial Lake Nicolet, after the first explorer of the region, existed at the same time as the larger Lake Chicago, and it is probable that when the ice melted out of the northern ends of Green Bay and Lake Michigan that the waters of the two mingled. It is possible that at one stage the entire drainage of the Lake Chicago passed through Lake Nicolet and out through the Wisconsin river.

CHAPTER VII.

NORTH CENTRAL WISCONSIN.

After the preceding general description of the surface of the state it is possible to discuss somewhat more in detail several areas of especial importance. As stated above it is practically impossible to divide the state into superficial regions which will be equally adaptable to the pre- and postglacial surfaces, so that it seems best to divide the state by more or less arbitrary lines which will include within each division the assemblage of characters most nearly similar. On this basis it is possible to recognize North Central, Eastern and Southwestern Wisconsin. North Central Wisconsin is almost coincident with the Old Land of the state, but a considerable portion of the Inner lowland is also included. It is largely composed of crystalline rocks and sandstone and is covered by the drift of the first ice invasion and of the last Wisconsin invasion. Eastern Wisconsin is composed of sedimentary rocks dipping to the east and covered by the drift of the last Wisconsin invasion. Southwestern Wisconsin is composed of horizontal sedimentary rocks and has no drift upon its surface.

The main portion of North Central Wisconsin is composed of the hard, crystalline rocks of the Old Land; from it and its continuation beyond the limits of the state, in Minnesota and Michigan, were derived the sediments which when spread out upon the floor of the surrounding ocean built up the rocks of the other parts of the state. It is the last remnant of the Isle Wisconsin, of Chamberlin, which was a part of the first land of the earth to hold its head above the waters of the primordial sea and afford a nucleus around which gathered the rocks which in process of time built up the North American continent. The rocks are granites, dolerites, gneisses and schists, lavas, and so forth, all hard rocks which resulted from the cooling of the originally molten mass. With these are highly metamorphosed sediments of the later part of the Archean time. Since the original lavas were cooled and the earliest sediments were laid down the region has been bent and folded, twisted and broken, and shot through and

through many times by lava flows of later date; the result has been that all the original rocks have lost their first form and have been changed into something else, metamorphosed. The pressure that caused the crumpling and breaking of the rocks and the heat of friction produced in the movement, with the heat of the lava intrusions, baked and compressed the rocks until they were softened and moulded into new forms, the sandstones into quartzites, the limestones into marbles, the shales into slates and the igneous granites and dolerites, and even some of the sedimentaries, into gneisses and schists.

Great interest attaches to the igneous rocks of central Wisconsin, for it is possible that we have here a representative of the earliest portion of the earth's surface, perhaps a portion of the original crust of the earth formed by cooling of the original molten mass. It is not at all probable that the rocks as they stand today are as they were when first formed, or that all of the rocks of the region belong in this class, but it is believed that certain of the fine-grained granites and schists are parts of the earliest solidified material, though they may have been remelted and moulded into different forms once and again; they are described by some authors as the much modified and metamorphosed rocks of the original crust, but still the same in mineral composition and texture.

When this portion of the state was first raised above the sea, and all during Archean time, it stood as a range of high mountains, but during the long time immediately preceding the Cambrian the surface was so worn down by the attacks of the weather that it was reduced to a great peneplain; the lofty peaks and domes were reduced until they stood above the general surface only as low hills and knobs, or ranges, of slight altitude, and isolated masses which resisted the degradation longer by reason of greater initial hardness or better protection by capping masses. Such are the low "iron ranges."

The crest of the state between the north and the south slopes passes through this region not more than 1,000 to 1,200 feet above the level of Lake Superior and about thirty miles south of its shore. There is nothing to indicate that the dividing line between the water-shed of the Mississippi valley and the St. Lawrence valley has been reached, for the land is very flat and the covering layer of glacial material is heaped irregularly upon the surface, hiding the native rock and confusing the drainage so that the rivers have no definite course, but pass in a maze from one or swamp to the next, and it is often impossible to say whether one is on the headwaters of one stream or another; on

the slope that drains to the Gulf of St. Lawrence or to the Gulf of Mexico. Indeed, several streams that find their way into these widely separated bodies of water are known to rise from the same swamps and lakes, e. g., the headwaters of the Montreal river and those of the Flambeau, a tributary of the Chippewa. In the northwestern portion the surface is marked by two ridges which have exerted a marked influence in determining the present topography of the region. Both run in a general northeast-southwest direction, but approach each other at the southern extremity until they finally join. The easternmost is the southern end of the ridge which continues into Michigan as the Penokee range and forms part of the backbone of the Keweenawan peninsula; the western one forms the backbone of the Bayfield peninsula. These ridges were prominent features of the surface even in the earliest times, so that, in the great period of post-Archean degradation before the deposition of the Cambrian sandstone, they remained as low ridges with a deep valley between them to the north, and when the land sank at the beginning of Cambrian time the valley became a bay and in this bay was deposited the sandstone, reaching here much farther to the south than at any other part of the shore line. The subsequent excavation of the sandstone by the rivers, and especially, perhaps, by the ice, has formed the deep indentation in the Superior shore, terminating in Chequamegon Bay, between the Keweenawan and Bayfield peninsulas.

The extension of the Penokee range into Wisconsin divides into three distinct parallel ridges or ranges before it joins the ridge of the Bayfield peninsula. These are called, in Wisconsin, the Penokee range (this was named by Whittlesey, in 1863, the Pewabik range (an Indian word meaning iron), but the name was changed by a printer's error to Penokee), the Granite (or Gabbro) range and the Copper range. These ridges have been developed by the action of the rivers on the upturned edges of the rocks wearing out the softer rock into valleys and running parallel to the upstanding hardened rock and then breaking across the hard rock in short stretches.

The Penokee range is the highest of the three, rising by an abrupt face from 200 to 300 feet above the surface to the south of it. The north face is not so abrupt, probably because the glaciers moving from the north have piled the drift up against it, forming more of a slope. The Granite and Copper ranges are less prominent than the Penokee range, being made up of a series of short discontinuous ridges, possibly the remnants of once more continuous ones that have been dissected by

river erosion. The Copper range rise abruptly from the lowland to the north and marks the beginning of the belt of ridges. Grant suggests that there is a fault here and that the steep face is the fault scarp. This steep face forms the Superior shore line at the mouth of the Montreal river, but gradually retreats to the south as it continues westward to join the Bayfield ridge. It is in crossing this steep face that the rivers flowing north from the flat top of the highlands to the lake pass from their former sluggish course through the swamps into falls and rapids.

The portion of the region between the ridge and the shore of the lake is thus described by Grant (Junction of the Lake Superior Sandstone and the Keweenawan Traps in Wisconsin, Bull. Geol. Soc. Am., Vol. 13): "In passing southward from the west end of the lake one crosses a monotonous plain which abuts against the east and west ridge, known as the Douglas Copper range. The north slope of this ridge is abrupt, and its summit is 100 to 300 feet above the plain. The plain is underlain by the Lake Superior sandstone in horizontal beds, and the ridge consists of lava flows dipping steeply toward the south. The sandstone in general is not firmly cemented and it is easily eroded, while the traps or lava flows are much more resistant to erosion. The abrupt northward slope of the trap ridge functions as a fault scarp, although by this statement it is not meant to convey the idea that the faulting has been recent nor that erosion has not kept pace with it; on the other hand, the present scarp is regarded as the result of differential erosion."

The Iron Ore Deposits.— The occurrence of the iron deposits in the Penokee Range is described by Van Hise.* The following description is adapted from his report. The Penokee-Gogebic Iron district is the only one which enters the state of Wisconsin. It is "a narrow belt south of Lake Superior running about N. 70° east, from somewhat west of longitude 91° nearly to longitude 89° 30', and between latitude 46° and 46° 30'. The eastern and most profitable third is in Michigan and the western and less profitable two-thirds in Wisconsin. The more important mining towns of the district are Hurley, Ironwood and Bessemer." Hurley and Ironwood are in Wisconsin and Michigan respectively and are only separated by the state line, which is here formed by the Menominee river.

The geological formations of the region are thus summarized:—

"1. Cambrian, which in the Lake Superior region, is mainly represented by the Lake Superior sandstone.

2. The Keweenawan or copper-bearing series, consisting of two divisions, the rocks of the lower division being largely igneous, but containing interstratified sediments, and those of the upper series, being wholly sedimentary.

3. Upper Huronian, mainly a sedimentary series, but locally containing a great series of volcanic rocks and cut by intrusives of upper Huronian and Keweenawan age.

4. The Lower Huronian, consisting mainly of sedimentary rocks, but in certain districts including volcanics. This series is cut by intrusive rocks of Lower Huronian and later ages.

5. The Archean or Basement complex, composed mainly of ancient igneous rocks, both plutonic and volcanic, but apparently including subordinate amounts of sediments. Into these very ancient rocks later igneous rocks of many kinds have been intruded at various times."

In tabular form the formations appear as follows:—

Cambrian	Lake Superior sandstone.
Unconformity. (An unconformity represents a break in the geological record.)	
Keweenawan.	
Unconformity.	
Upper Huronian (Penokee-Gogebic series)..........	Tyler's slate (upper slate formation). Ironwood formation (iron bearing formation). Palm's formation (quartz slate formation).
Unconformity.	
Lower Huronian	Bad Limestone (Cherty limestone formation).
Unconformity.	
Archean	Granite and granitoid gneiss. Schists and fine-grained granite."

The very mixed relations of the various beds can be appreciated from the descriptions given above, but they have been

further complicated by numerous faultings and foldings which delayed the deciphering of the true relations for a long time and which is by no means completed even now. Reduced to its simplest terms, it is a region of highly metamorphosed originally horizontal rocks which have been folded and faulted and shot through in all directions with lava flows, dikes and seams.

A dike is formed when a mass of lava below the surface of the earth forces itself across the strata at a more or less acute angle, and, hardening in the openings formed, leaves a mass of hard rock interrupting the continuation of the strata. It comes to the surface in a long line, and if harder than the surrounding rock may resist weathering longer and stand up as a ridge, and if softer it may erode faster than the surrounding rock and leave a depression. The former case is much more frequent than the

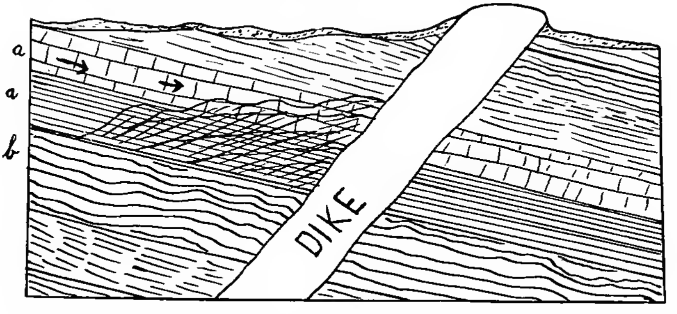


Fig. 26. Cross section of a dike cutting through sedimentary rocks. a, a, porous, water-bearing layers; b, impervious layer; the water runs down the porous layer until it collects in the trough formed by the meeting of the impervious layer and the dike. The dike appears on the surface as a prominence due to its superior resistance to erosion.

latter. Such dikes may run in any direction across the strata and may be single or may break into many branches. Where they outcrop on the surface they are generally referred to as trap dikes.

The circulation of the underground waters in the iron regions is interfered with and largely controlled by the presence of these dikes cutting across the water-bearing layers and by the presence of impervious layers of slate and quartzite which lie above and below the pervious layers which act as conduits.

The waters of the air, rain and snow, carry down into the rocks large quantities of oxygen and carbon dioxide; these in combination with the water attack the iron-bearing minerals of the igneous rocks, the mica, hornblende and feldspar and break them up, forming large quantities of iron oxide, ordinary iron rust, or hematite, F_2O_3, and limonite, $Fe_2O_3+H_2O$, both of which are quite soluble in water. The water bearing the dissolved iron oxide finds its way into the porous layers and coming in contact with the impervious layer below runs along its surface, flowing through the porous layer as through a veritable conduit. Following the slope of the strata the water continues its course

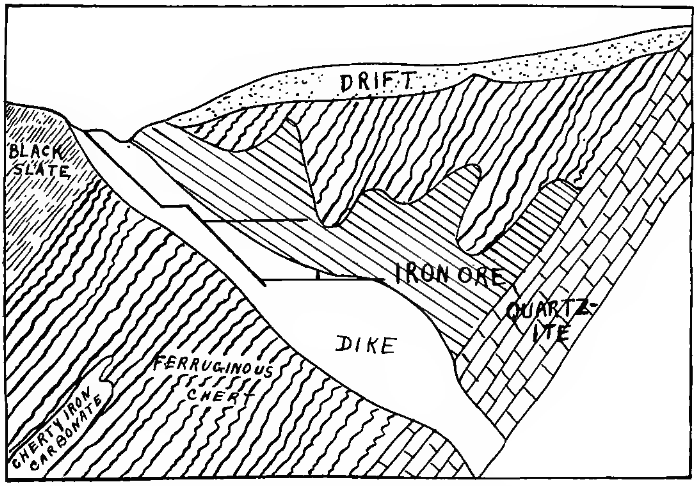


Fig. 27. Generalized section through the Colby mine at Bessemer, Michigan, illustrating the formation of the iron ores in the Penokee-Gogebic district. The iron ore is deposited in the trough formed by the meeting of the dike and the impervious quartzite. From Van Hise, Leith and Smyth.

underground until it comes in contact with one of the dikes which runs across the strata forming an obstruction to its further progress. Where the impervious layer below the water bearing one comes in contact with the dike the two form a trough which has generally a slant at right angle to the slope of the

stratum down which the water flows, so when the water in the porous layer meets the dam across its path it fills up the porous layer to form an underground pool or turns and flows parallel to the face of the dike which interrupted its progress. It is in such pools or streams collected in the trough formed by the dike and the impervious layer that the great iron deposits have accumulated, both as beds of pure hematite and as impregnations of the native rock. The outcrop of the dikes on the surface of the ground generally stands higher than the surrounding surface because of its superior hardness, and forms low lines of hills from 200 to 300 feet high; these are the iron ranges. It will be seen at once that the ore does not occur in the range, but to one side of it.

In the Menominee range, which enters very slightly into the state, the underground trough in which the water bearing the iron collects and deposits the ore, is formed by a long fold in the impervious and pervious layers without the presence of a dike. Much of the movement of the water in this region is along lines of contact between the more or less pervious layers, where openings have been formed by the separation and fracturing due to folding and faulting.

In general, according to Van Hise (21st Annual Report Director U. S. Geol. Survey): "Within the iron bearing formations the large ore bodies are very generally found with the following relations: (1) They rest upon an impervious basement; (2) this impervious basement is commonly a pitching trough*; (3) the ore formation is usually much plicated and broken; (4) the majority of the ore bodies occur below crests or slopes, not below valleys."

"The Menominee district extends from the Menominee river in a direction about E. 60° to 70° S. It crosses longitude 89°, and lies between latitude 45° 45′ and 46°. The area which has been mapped is about 20 miles long and on an average about 6 miles broad. The Huronian belt has not been mapped farther to the east because it is capped by the Cambrian sandstone. It has not been mapped west of the Menominee river because of the overlying Pleistocene (Glacial)."

*A pitching trough is where the trough is inclined so that the long axis lies at a slant, as the gutter on a roof is inclined to permit the water to run off.

The detailed section of the iron bearing formations of the Menominee district is thus given by Van Hise:

Silurian and Cambrian	Hermansville limestone. Lake Superior sandstone.
Unconformity.	
Upper Huronian (Upper Menominee series)	Hanbury slate, bearing in lower portions calcareous slates, and containing siderite and iron oxide. Vulcan formation, consisting in descending order of three members: (a) Curry member (iron bearing); (b) Brier slate; (c) Traders' member (iron bearing).
Unconformity.	
Lower Huronian (Lower Menominee series)	Negaunee formation (in small patches). Randville dolomite. Sturgeon quartzite.
Unconformity.	
Archean	Granites and gneisses. Quinnesec schists.

VAN HISE'S SUMMARY OF THE GENESIS OF THE ORES.

"As to the genesis of the ores, the cherty iron bearing carbonate is the main original rock. This is found in every district in the entire Lake Superior region, with the exception of the Mesabi district, where iron silicate is very important. The rocks are metamorphosed along two main lines. The first of these lines produces amphibolitic and magnetic quartz rocks or schists, and occasionally also pyroxenitic and chrysolitic rocks. These rocks develop under deep seated conditions in connection with igneous intrusives, and especially the basal gabbro intrusives of the Keweenawan. Where the iron bearing formations have thus been altered no workable ore bodies have as yet been found. The second line produces ferruginous slates, ferruginous cherts, jas-

pilites, and ore bodies. These rocks develop mainly in the belt of weathering, although in many cases the production of the jaspers required two stages—first the formation of the ferruginous slates and ferruginous cherts in the belt of weathering, and later dehydration when the formations were deeply buried.

"In a number of the districts in which the Lower Huronian iron bearing formation occurs the upper part of the formation was exposed to weathering before Huronian time. When the Upper Huronian sea transgressed over these iron bearing formations detrital ferruginous sandstone and conglomerate were produced, which, so far as they contain iron oxide, are on their way toward ore bodies. To some extent, also, the ore bodies are due to the oxidation of the iron carbonate in place. But all of the facts irresistibly lead to the conclusion that the final and most important step in the formation of the ore bodies was secondary enrichment by downward percolating of waters below crests or slopes where such waters were converged by the pitching troughs. The waters which followed the more circuitous routes transported iron carbonate; waters more directly from the surface, which did not pass through iron carbonate, bore oxygen; the two kinds of solutions mingled and precipitated iron oxide. The waters ascended and escaped below the valleys. Finally, the great quantity of water which was converged in these troughs and moved downward abstracted the silica and carried it elsewhere.

THE QUANTITY OF IRON ORE AVAILABLE.

"If the foregoing reasoning is correct, it is perfectly clear that the ore bodies cannot be expected to extend beyond the depth to which the descending waters may bear oxygen and precipitate iron oxide. Up to the present time all but an insignificant fraction of the ore has been taken from above the 1,000 foot level. Many ore deposits before reaching the 1,000 feet of depth have become smaller and poorer, and a number have been worked out. Two or three ore deposits have been sufficiently persistent, so that they have been worked to the depth of 1,500 feet, but the great majority of deposits, even in the oldest districts in which there has been time for deep development, has not been worked to such depths as this. I have no doubt that vastly more high grade ore will be taken out in the Lake Superior region above the 1,000 foot level than below it. If this be true, iron ores of the Lake Superior region bearing more than 60 per cent of metallic iron are not inexhaustible. Indeed, a very appreciable percentage

of such ores yet discovered has already been exploited. But high grade ores are not the only source of supply.

"Thirteen years ago (before 1901) practically all the material shipped from the Lake Superior region contained more than 60 per cent of metallic iron. For the last five years large quantities of ore have been shipped from the ranges south of Lake Superior containing less than 60 per cent, and considerable quantities of ore have been shipped running from 40 to 50 per cent metallic iron. If all the material be called iron ore in which the percentage of iron is 50 per cent or more, with an average amount of phosphorus, a large quantity of material left behind, wasted or not developed, would be ore. If material be called iron ore which runs more than 40 per cent metallic iron, and this material would be ore in Europe, this would add greatly to the amount of available ore.

"Already some low-phosphorous, high-silica ores which bear no more than 40 per cent metallic iron have been marketed for mixture with Mesabi ores. I have no doubt that within another generation a considerable proportion of the material shipped from the Lake Superior region will run between 40 and 50 per cent metallic iron, and that low-phosphorus, high-silica ores containing considerably less than 40 per cent metallic iron will be marketed.

"The exhaustibility of the high grade iron ores of the Lake Superior region cannot be too strongly insisted upon, for belief to the contrary almost invariably results in lack of foresight and waste on the part of the operators. The policy of mining only the richest ores which can be marketed today, and frequently in handling this material in such a manner as to make it difficult to recover the somewhat lower grade material at a later time, is a very shortsighted policy, even from the point of view of the mining men, and ignoring the future of the nation. The sagacious policy is to treat the low grade ores which cannot be marketed at the present time as a resource which will certainly have a value in the future. Moreover, taking into account the enormous increase in the quantity of ore mined, I have no doubt that the demand for the low grade ores which are at present completely ignored or wasted will come much sooner than mining men believe. The total product of the Lake Superior region since mining began in 1850, to 1900 inclusive, is 171,418,984 long tons. The amount mined in the decade between 1891 and 1900 inclusive is 114,017,546 long tons, or 66.5 per cent, or nearly seven-tenths of the total amount mined. The product for the year 1900 surpasses that of any previous year and is one-ninth of

the aggregate of this and all preceding years. It is certain that the product of the present decade will far surpass that of the last decade.

"The mining men should seriously consider how many decades supply such as that of 1891 to 1900 of high grade material is in sight, or even discoverable, on the United States side of the boundary. If this amount be placed at 1,000,000,000 long tons, mining at the rate of 20,000,000 long tons per year would exhaust the supply in the first half of the twentieth century, or in about the same length of time that mining has been carried on in the Lake Superior region. The exhaustion within a few decades of the high grade ore of the Lake Superior region now discovered is little short of a certainty. It is therefore plain that the material in which the percentage of iron is below the present market demand and which must be handled in connection with present operations should be stock piled, and that the mines be developed and exploited with the expectation in a comparatively short time of mining material running between 50 and 60 per cent of metallic iron, and within comparatively a few decades of material running between 40 and 50 per cent of metallic iron."

The Great Peneplain.—It will be remembered that toward the close of the Archean time the surface of the state was reduced to a peneplain cut by the rivers in the hard igneous rocks. The land has repeatedly been raised and lowered since that time, but there has been no folding or breaking, no distortion due to mountain making, to disturb the level of the surface, so that it is still traceable on the southern slope of North Central Wisconsin. The peneplain is most distinctly apparent in Taylor, Lincoln, Marathon, Portage, Wood, Clark and Jackson counties, but there is good reason to believe that it extends far to the north through Michigan and Canada west of Hudson's Bay, where it is obscured by the heavy growth of evergreen trees, and south under the sedimentary deposits of Wisconsin and Illinois. The following description of the peneplain is taken largely from Weidman's report on the subject. (The pre-Potsdam peneplain of the pre-Cambrian of North Central Wisconsin. Jul. Geology, Vol. II, 1903.)

Taking Wausau as the central point, a careful examination of the horizon line formed by the tops of the surrounding hills shows that there is a surprising similarity of level. This is especially true if the examination is made from the summit of the hill to the northwest of the town; from there, overlooking the immediate foreground, the essential plan of the horizon is strik-

ing. A more careful study shows that the hill tops to the north of the town are uniformly rising, so that the surface which would be produced by connecting the hill tops would be a flat plain tilted to the south. The hills are remnants of the higher land and their summits are portions of its former surface, the valleys between the hills mark the present stage of its degradation. The rocks forming the hills are the crystalline igneous rocks of the old land and wherever they appear in the sides of the hills or in the river beds of the valleys the folding and foliation, the bendings and contortions tell that the region was once mountainous. The plain formed in this mountainous country as indicated in the hill tops was cut cross the folds and contortions independent of their direction, so it is evident that it was produced by degradation of the land down to a common level in all parts, beveling across the folds and leaving only the upturned edges to tell the story of their former height and shape. And now a second cycle of degradation is in progress, for the surface is far above the base level of the present rivers and they are cutting down towards that level; the land has been raised without folding, but as a board is raised, more at one end than another, so that the north end is higher than the southern and the rivers are cutting deep channels with wide valleys. So far has this work of the rivers gone that more of the original plain is gone than is left and instead of an elevated plain with incised river valleys it appears rather as a lowland with isolated hills.

Fig. 28. Diagramatic view of a region that has been reduced to base level and then rejuvenated; the rivers have cut valleys, forming isolated hills whose even tops indicate the former level of the land. The highest hills indicate prominences above the general level of the peneplain.

Weidman's description of the region is as follows: "The pre-Cambrian area was once a mountainous region; subsequently the mountainous area was worn down by erosion to a peneplain, and must necessarily have been near sea level. At a much later

period the peneplain was uplifted to its present elevation, and again subjected to a period of erosion which has continued to the present day. Out of this ancient plain of erosion the present valleys about Wausau are seen to be in process of construction, and hence the region may be described as a dissected peneplain."

Directly south of Wausau several hills, the Mosinee hills, Rib hill and Hardwood hill rise above the general level of the surrounding hill tops; they are remnants of great mountain masses which persisted upon the old peneplain, having resisted the processes of wear for some reason, probably superior local hardness, so that they were not reduced to the general level, and even now in the second cycle of erosion they persist and preserve the history of the region back to the second earth cycle preceding. Such hills remaining above a general level which has been produced by erosion because of local hardness or better protection of a capping layer, are known as Monadnocks, from the mountain of that name in New Hampshire, which has such a history. The Baraboo ridge and the Blue and Platte mounds in the south, and the Iron ranges in the north, have a similar history.

Following the plain formed by the hill tops to the south, it is seen that it gradually dips beneath the horizon and, with the Archean rocks, disappears from the surface beneath the Cambrian rocks. The story is evident: While the Archean land was still the only land of Wisconsin and reached much farther south, it was degraded to a peneplain and in the subsequent movements of depression which converted southern Wisconsin into a continental shelf the plain was tipped, so that the waters of the Cambrian ocean overflowed a very considerable part of the state and buried much of the Archean surface under layers of its sandstone. The Archean rocks disappear under the Cambrian sandstone in the vicinity of Grand Rapids, Neillsville and Pottsville, but their occurrence farther south is shown by small prominences of crystalline rocks sticking up through the sandstone in the vicinity of Arpin, in Wood county, and by their exposure in the beds of the small streams that have cut their valleys down through the sandstone.

Farther south it is only in the beds of the larger streams with deep valleys that the hard rock is exposed, showing that it continues to slope to the south and to be more and more deeply buried; such exposures occur in the bed of the Wisconsin river from Grand Rapids to Nekoosa; it is the prominence of the hard rocks in the beds of the river that forms the frequent falls and rapids of this portion of its course. Beyond the points of its exposure the presence of the flat slanting surface is indicated by

drill holes as far south as Oshkosh, Fond du Lac and even Madison, for the Archean is struck at regularly increasing depths as we go south.

The story of the great Archean peneplain is emphasized by the condition of the rivers and their valleys. North of Merrill the Wisconsin river runs in the confusion induced by piles of glacial debris, sharp valleys cut in the drift alternating with indefinite stretches lost in the mazes of swamps. Between Merrill and Wausau the valley is cut deeply in the old Archean rock, forming wide bottomed valleys with steep sides from 200 to 300 feet high. From Wausau south the valley becomes more shallow until at a point 20 miles south it is only 100 feet deep and finally,

Photograph Showing the Surface of the Great Pre-Cambrian Peneplain near Wausau. Photo by Weidman

at Grand Rapids, it runs out onto the soft Cambrian sandstone and the banks are very low. The tributaries of the Wisconsin at this point, the Big Rib, the Big and Little Eau Pleine, the Pine, the Trapp, and the Eau Claire rivers, have wide bottomed, steep sided valleys at their mouths where they run into the Wisconsin and narrower sharp valleys toward the headwaters where they run over the Archean rocks. Southward, in the sandstone, the tributaries like the main stream run in flat valleys with low banks.

The presence of the peneplain was recognized by Van Hise in 1896; he considered it as extending on the surface far to the

north and the south of the regions here described. There seems little doubt that it can be traced to the north limits of Wisconsin and from there into the Upper Peninsula of Michigan and indefinitely north into the swampy regions in the southern and northwestern portions of Canada. Van Hise thought that it also extended to the south into the driftless area, but, as shown above, Weidman has demonstrated that it passes under the sandstone at Grand Rapids and is a buried peneplain beneath the Paleozoic of the southern part of the state.

The Barrens.—In the western part of this region there are extensive areas of glacial sand formed by sheet floods during the retreat of the glaciers from the land. These are "aprons" or "overwash plains" formed, as explained above (p. —), and are locally known as the Barrens or Pine Barrens. They are strips of light sand from 12 to 15 miles wide and nearly 125 miles long, extending from the Bayfield peninsula well down into Polk county. There are several more or less parallel areas rather than one, but they have all the same general direction and the same origin and character. The loose sand and gravel readily permits the water to pass into the ground, so that in the portion which is crossed by the terminal moraine and where the sand is very deep, as in towns 45-49, ranges 6 to 10 west, mostly in Bayfield county, there are few streams on the surface, the waters sinking into the soil and reappearing at the edge of the district. Such streams as the Brule, Flag and Iron rivers originate in this way; their headwaters are either springs or small lakes which are fed by small bottom springs.

The Rivers of North Central Wisconsin.—The north slope of the Archean land mass passes abruptly at its bottom into the sandy lowland which forms the shore of the lake. The line of demarcation between the two is considered by Grant to be the fault scarp on the north side of the Douglas range. The sudden transition from steep slope to gentle, and from hard rock to soft sandstone, has a marked effect upon the course of the streams which flow north into Lake Superior.

In describing this slope Smith says (Water Supply and Irrigation Paper No. 156, U. S. Geol. Survey):

"The Lake Superior Drainage System.—The water shed which limits the area of Lake Superior drainage in Wisconsin varies in elevation (above the level of Lake Superior)

from 600 feet near the Minnesota line to over 1,000 feet near the Michigan line. Its average distance from Lake Superior is only 30 miles. For this reason the rivers are comparatively small; but, owing to the fact that their high gradient, 600 to 1,000 feet, is largely concentrated at a few points, they offer many opportunities for water power development. From a point near the center of the watershed a wide and nearly flat tableland, of which Bayfield peninsula and the Apostle Islands form the northern prolongation, separates the drainage into eastern and western sections of nearly equal area. In both of these sections three distinct belts of topography are usually distinguished. The southernmost belt consists of a plateau in large part covered with swamps and lakes and is so flat that in many cases the water from the same swamps and lakes may flow either north to Lake Superior or south to the Mississippi.

"From this flat watershed the descent northward is gradual until a range of mountains from 600 to 900 feet above the level of Lake Superior is reached. The northern slope of these mountains is much steeper than their southern slope, forming a marked though not continuous escarpment.

"In the western section these mountains, known as Douglas Copper Range, reach a height of 400 to 600 feet above the lake and have a width of 1 to 4 miles. They extend in an east-northeast direction, gradually merging into the Bayfield moraine. From the crest of the mountains there is a sudden descent of 300 to 400 feet, caused by a faulting of the rocks. The Lake Superior rivers break through the ridges at this point, and here the greatest opportunities for water power development are to be found.

"In the eastern section the mountains, called the Penokee Iron Range, extend from a point on the Michigan boundary, 12 miles from Lake Superior, in a southwesterly direction for about 35 miles, gradually merging into the plateau. As in the western section, many falls and rapids occur in breaking through the hard Huronian rocks of which the range is composed. Smaller faults continue for a distance of 5 to 6 miles after crossing the Penokee range, or until the Copper range has been crossed.

"To the north of the highlands and extending with a gradual slope northward to the shores of Lake Superior, lies a plain with a width of 5 to 15 miles. This northern portion reaches an elevation of 100 to 200 feet above Lake Superior or 700 to 800 feet above the sea. The entire belt is underlain by till and deep layers of red clays, sometimes mixed with sand. The rivers, both large and small, have cut deep and narrow banks in the clay soil. As

a result the surface is carved in every direction by narrow water courses whose steep sides have a height of 25 to 100 feet, making railroad and highway construction expensive. Very few swamps are found in this lowland area. Because of the gradual slope of the shallow rivers opportunities for water power development in this belt are rare. In many cases, however, there are important falls at the immediate mouths of the rivers and over the red sandstone."

Bad river differs from the other streams of the region in carrying a notable amount of sediment. Its headquarters are in the marshy uplands forming the crest of the Archean land, 8 miles south of the Penokee Iron Range, from which it flows in a sluggish and indeterminate course. Near the middle of its length the slope of the bed becomes very rapid, 25 to 30 feet per mile, and there are many falls and rapids interrupting the course of the water and many narrow gorges in the granite confining them to a narrow channel. At the end of the granite the stream is again more sluggish as it runs out onto the sandstone flat, where after passing over a series of low falls it ends in the swamps and marshes formed by its deposits on the border of the lake. Formerly the river opened into Chequamegon Bay, but the constant accretion of its deposits in the shallow water built up bars and a delta which finally completely stopped the course of the stream and compelled it to seek a new opening directly into the lake.

The St. Louis river is the second largest river which empties into Lake Superior; its lower 19 miles, from the village of Fond du Lac to the mouth, forms the boundary between the states of Wisconsin and Minnesota. This portion of the river has a very slow current, the channel is wide and dotted with islands, but it is navigable to small boats beyond the borders of the state. The banks are low on the south, with wide flood plains and no rocky walls until about the state line, where the banks rise in bluffs of the Lake Superior sandstone. The Minnesota shore is more abrupt, with bluffs of sandstone and Archean crystalline rocks. Beyond the limits of the state the scenery of the river becomes wild and beautiful, where the river descends 456 feet in 6 miles over falls and rapids. The headwaters are again sluggish and flow through swamps and lakes.

The Brule or Bois Brule, the Middle, American and Black rivers are the most important streams between the St. Louis river and the Bayfield peninsula. They all head in the swampy land at the crest of the state and pass through swamps filled with tamarack and closely connected small lakes until they reach the edge of the ranges of hard rock, where they become more

rapid and pass over falls and rapids and through gorges onto the sandstone of the lake shore. The falls, especially of the Black and Brule rivers, reach a considerable height. The original describer of the falls of the Black river speaks as follows: "The river is about 40 feet wide and falls into a circular basin about 60 feet in diameter; a large mass of rock on the brink of the precipice, midway the stream, divides the water into two chutes, and adds greatly to the picturesque appearance of the falls." Through the sandstone the Black river has cut out gorges 100 to 175 feet deep; the other streams have cut similar gorges, but of less depth.

The Montreal river rises in the upland swamps where its headwaters mingle with those of the Flambeau, the chief tributary of the Chippewa; it drains a smaller area than the Bad river, but carries nearly as much water. It has a less precipitate course than the Bad river, but near the shore passes over a fall 78 feet in height in two jumps and then through a gorge cut in boulder conglomerate, whose sides are in places as much as 100 feet above the river. Close to the lake there is a fall of about 90 feet over sandstone and shale and then the river passes through a gorge with 90 foot walls to the lake.

The Dalles of the St. Croix.—The St. Croix basin occupies the western part of the highlands and in part the sandstone lowland which lies to the south; the lower part of the basin is crossed by the terminal moraine, so that the extreme lower part lies in the region of the earlier drift and the upper part in the region of the later drift (see map, p. 62).

The river heads in the Upper St. Croix lake, near the center of Douglas county (only 20 miles from Lake Superior) and flowing southwest soon forms the boundary between Wisconsin and Minnesota, until it empties into the Mississippi river at Douglas Point, in Pierce County. It is naturally divided into three parts —the Upper, Middle and Lower St. Croix. The Upper part extends as far south as about the northeast corner of Chisago county, Minnesota; from there to a point called Prairie Hollow, 4 miles southwest of Osceola, Wisconsin, is the Middle part, and below this point to the mouth of the river is the Lower part. The different portions of the river present very different phases and their true history has not been fully made out; the ideas presented here are those which seem to have received the greatest acceptance.

It is probable that in the preglacial time there were two rivers draining the region instead of one. The northern one was formed by what is now the Upper St. Croix and that portion of

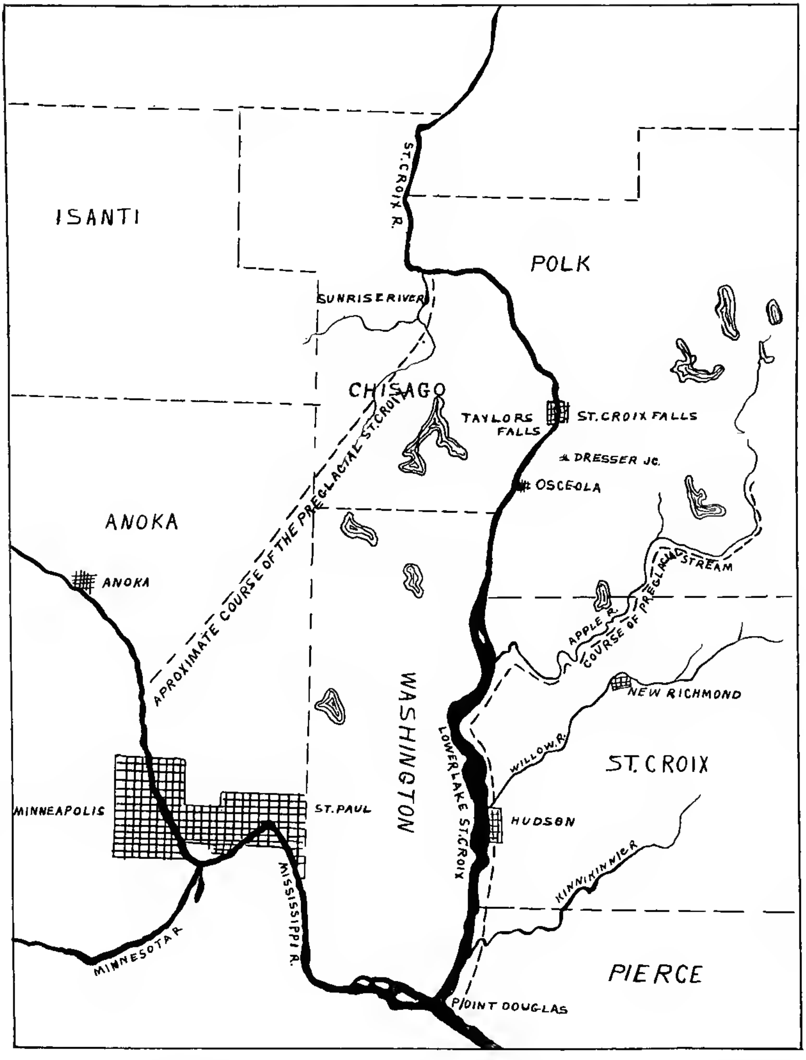


Fig. 29. Sketch map showing the relation of the present St. Croix river to the preglacial drainage. From R. T. Chamberlin.

the middle part to about where the Sunrise river of Minnesota enters the St. Croix, it was continued south and southwest until it joined the Mississippi somewhere between Anoka, Minnesota, and Minneapolis.

The southern river was located very close to, if it was not really coincident with the present Apple river, and the portion of the Lower St. Croix below the mouth of the Apple river.

Due to the deposits of the glaciers the northern stream was deflected from its preglacial course and turned more directly south until it joined the preglacial Apple river and reduced the headwaters of that stream to the condition of a tributary. The cause of the division into Upper, Middle and Lower portions is now very clearly seen; the Upper and Lower portions are preglacial in origin and consequently very much older than the Middle portion, which is postglacial. The Upper St. Croix flows through the swampy upland and finally passes into a wide and relatively deep preglacial valley, which is, however, largely filled with and obscured by accumulations of glacial drift. The Lower St. Croix flows in what was an old and wide preglacial valley, but which is now even wider and deeper than would seem necessary for such a stream. Its condition is probably explainable as follows: It is supposed by Upham to have been the outlet of the extension to the south of the waters of Lake Superior in the time of the disappearing ice, the Western Superior or Duluth lake, just as the Minnesota river was the outlet of a great lake over the present valley of the Red River of the North. Both of these rivers carrying the overflow from such enormous bodies of water had a much greater volume than today and dug channels commensurate with their size, forming valleys wider and deeper than are proportionate to the present volume of the rivers. The great volume of water poured into the Mississippi by the Minnesota increased the cutting and carrying power of the latter, so that it eroded out its channel much deeper than is demanded by the present stream. The Lower St. Croix and the Mississippi below the mouth of the Minnesota have had, then, a similar history; the increased volume of water which flowed through at the time they acted as the outlets of great lakes deepened and widened their channels, but since then as the lake waters have withdrawn and the rivers have lost the greater part of their volume and velocity the deeper portions of the channels have been converted into lakes of considerable size. The formation of these lakes has been aided by the action of the tributaries, for the main stream flowing slowly through the deeper part of its channel has not been able to carry away all the debris that has been brought

to it by the tributaries, so that the tributaries have formed deltas in the main stream, which have increased until they have formed a partial dam across the main stream, ponding back the waters

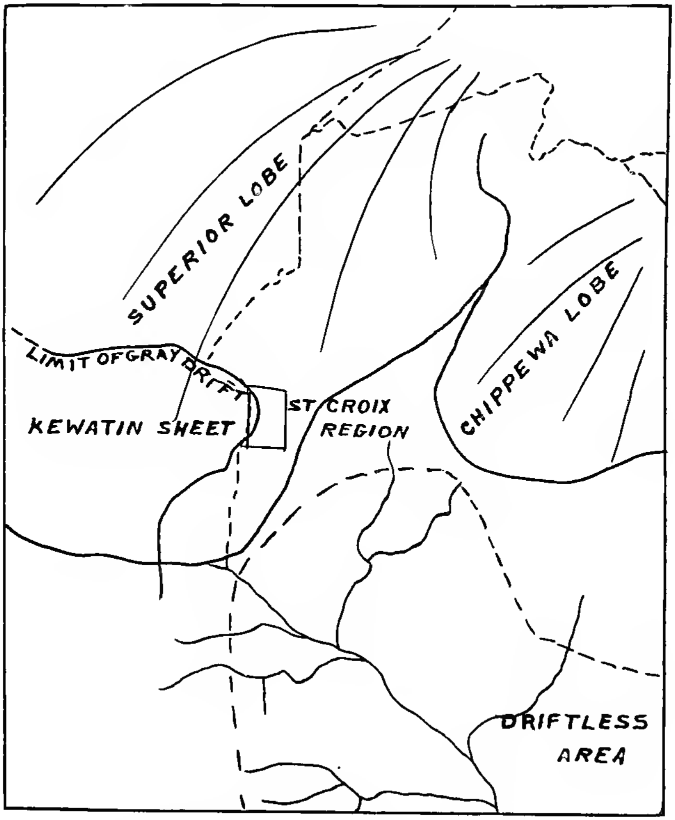


Fig. 30. Sketch map showing the position of the ice lobes during the last glacial invasion in the region of St. Croix Falls. After R. T. Chamberlin.

even more and deepening the lake. Thus has been formed the Lower St. Croix lake and Lake Pepin; in the latter case the

Mississippi has been partly dammed by the debris brought down by the Chippewa river.

The history of the Middle St. Croix is very different from the other portions. When the morainal material forced the stream from its original course to the southwest it turned sharply southeastward and began cutting a channel through the soft Cambrian sandstone; in the portion of the course above the St. Croix falls it has already cut down to the underlying Archean rocks. Where the river runs over the hard igneous rock it has done very little of its work and is still spending its energies in cutting down the bottom, so that the widening has not yet progressed very far; the result is that it runs in a narrow gorge between high and picturesque walls; this is the Upper Dalles of the St. Croix. R. T. Chamberlin in describing this portion of the valley says (The Glacial Features of the St. Croix Dalles Region. Jnl. Geol., Vol. XIII, 1905):

"Since the first well marked course was formed, the stream between Taylor's Falls and Osceola, where the most Keweenawan trap-rock was encountered, has migrated westward down the slopes of hard diabase and cut away the less resistant sandstone and shale. The slopes on the western side, opposite Franconia Station, for instance, are comparatively gentle, but the Minnesota bank is a steep cliff of Cambrian sedimentaries. A well developed channel, nearly parallel to the present course and about one mile east of it, can be followed from the bend in the river at the interstate park in Taylor's Falls to Osceola, where it joins the St. Croix today just below Eagle Point. It is not difficult to find the points at which this course was abandoned in the migratory process—first 2 miles north-northeast of Osceola at a barrier of Keweenawan, next 2½ miles farther upstream at a similar obstacle, again at Thaxter lake, and lastly at the elbow near Taylor's Falls, where, finding a deep rock fissure running northeast and southwest, more in line with the new course of the stream below, the opportunity was taken to readjust itself. Some readjustment is evident also above the Dalles in the immediate vicinity of the town of Taylor's Falls."

Berkey describes the features of the Dalles in his guide to the region (A Guide to the Dalles of the St. Croix for Excursionists and Students. Minneapolis, 1898) as follows:

"The prominent physiographic features presented by the action of the river are terraces, abandoned river channels, river lakes, river dams and a remarkable accompaniment of the erosion of the igneous rocks usually known as pot holes. (a) Terraces. There are five terraces to be seen in the immediate vicinity (of

Taylor's Falls). At about 905 feet above sea level the first or highest terrace forms a very prominent bench which is known in Taylor's Falls as the 'picnic ground.' It also occurs in more limited extent on the Wisconsin side of the river, near the railway station. It seems to be closely associated with the retreat of the ice from the vicinity. Succeeding ones, however, are simple river terraces and are quite as easily traced farther down the gorge.

"The second terrace follows the 810 foot contour line and is most easily studied on the east side of the river. It forms a comparatively narrow bench along which the main business street of St. Croix Falls is built, and may be traced throughout the village.

"At 780 feet on either side of the river a third terrace is developed to a considerable distance above St. Croix Falls.

"At 750 feet on either side of the river the fourth terrace forms the conspicuous and level tracts bordering the present river channel 50 or 60 feet above the water level. The business portion of Taylor's Falls is built on this terrace, and River street, as far as the upper falls, is a part of the same bench. Also on the east side of the river is the same terrace on which the mill is built, and on which the abundant spring water is collected to furnish its power.

"A fifth terrace at 725 feet has a very limited development near the toll bridge.

"(b) Abandoned channels. The St. Croix has been turned from its present course several times in its late history. Two abandoned channels are within reach (of St. Croix Falls), one of them of considerable importance and interest. A small side channel may be seen in Taylor's Falls near the freight depot. A large and well marked one extends southward from the elbow in the Dalles. It is about 2 miles long, reaching the river again less than a mile above and opposite Franconia. It was abandoned at the 800 foot contour, 100 feet higher than the present river level, upon reaching a bed rock of diabase, which made deeper erosion along its course extremely difficult and slow. The present channel lies considerably to the west and passes almost wholly through much softer sedimentary rocks.

"At a much later stage a part of this channel immediately next to the Dalles was still used. It is now marked by the river-lake Thaxter, which lies in the old channel at the level of the present river. At that time in the history of the river there must have been a considerable fall at this place, where the waters pouring over the igneous rocks plunged down into the easily eroded sandstones adjacent. A fall of 50 feet, and perhaps 100

feet, seems to be a reasonable estimate upon the evidences of filling of the abandoned Lake Thaxter channel and accompanying phenomena of erosion. The precipice forming the brink of the abandoned falls may be seen a little off the road leading to Thaxter lake, just below the elbow of the Dalles. The entrance to this channel is about 50 feet above the present river.

"(c) Pot Holes. At the Dalles, and also a mile above the Dalles, there are a large number of deep holes called pot holes worn into the hard igneous rocks. They are forming in the present river bed and are also found even more abundantly on the terrace-like benches to an elevation of more than 50 feet above the river level. They seem to have been an accompaniment of the destruction of these persistent rock barriers from the beginning of river erosion.

"In their best and most typical development probably few localities in America are more favored than this. And in few places also is the question of their origin more clear or their history more intimately connected with other questions of considerable importance. It seems clear from a study of the locality that all of these holes have been formed by swiftly running water, whose swirling eddies, produced by the unevenness of the rock floor, have carried sand and gravel around so persistently that great holes have been literally drilled into the hard crystalline rocks which formed the river bed. Each hole was then filled with a rotating column of water at whose top the onward flow of the river furnished power enough to keep it in rotation, and at whose bottom pebbles and sand and boulders rolled round and round year after year and century after century—boring the hole deeper and grinding the pebbles smaller—until the river deserted its task or accomplished the object of its toil. * * *

"At the close of the ice age the St. Croix carried an immense volume of water contributed by the melting ice of the retreating glaciers. As it was also at that time the outlet of Lake Superior, when that lake was 500 feet deeper than it is now, and when it drained into the Gulf of Mexico instead of into the Atlantic ocean."

The glacial history of the St. Croix region is of particular interest, even in Wisconsin, where glacial topography is the most common feature, for it is the only portion of the state which was visited by the western, or Keewatin, ice sheet. And even here the traces left by that sheet are very slight, for it did not advance over a mile into the state at the St. Croix falls and only about 4 miles at Osceola, the point of its maximum eastern extension.

Moreover it quickly withdrew, so that it did no great amount of erosion and left only a thin layer of till superimposed on the glacial deposits of the Lake Superior lobe to preserve the story of its Wisconsin invasion. The deposits of the two sheets are distinguishable by the fact that the glacier from the west passed over a limestone region and its debris is filled with calcareous material, giving it a light grey color, while the debris from the Superior lobe is colored red from the iron of the igneous rocks over which it passed.

Mr. R. T. Chamberlin has recently published an account of the glacial history of the region, from which the following is quoted:

"To get an idea of the work and relative importance of the two ice sheets, conceive of the glacier of the red drift, or the Superior (Labrador) glacier, as a vigorous, long enduring sheet, which produced most of the present topography, and of the glacier of the gray drift, or the Keewatin glacier, as a thin, transient advance of ice, which left as its record only a gray veneering of the red hills.

THE WORK OF THE SUPERIOR GLACIER.

"Whatever older drift there may be in this region has been so deeply buried under the thick Late Wisconsin deposits that no certain evidence of it was seen. The oldest glacial deposit thus far found is the red drift of the Lake Superior glacier. The first characteristic of this drift to catch the eye is its unusually red color, due to the presence of much ferric oxide. The unaltered till is very red; the stratified deposits from which the water has removed part of the coloring matter less so. Often the surface layer has been partially leached of its ferruginous compounds, which have concentrated below, leaving the soil a brownish color. Another distinguishing characteristic of this till is that it is prevailingly sandy, and only locally clayey, signifying that the path of the ice advance was over an extensive sandstone and crystalline rock area, and that little limestone or shale was encountered. Of like import is the fact that, while there is the lithological heterogeneity characterizing glacial deposits, the pebbles are confined to a group of rocks chiefly of igneous origin, such as diabase, basalt, serpentine, various porphyries, granite and crystalline schists, together with sandstone. Limestone pebbles are conspicuous by their absence. The basalts predominating, the till may be described as a reddish sandy formation containing chiefly dark colored igneous pebbles and boulders. The source of this

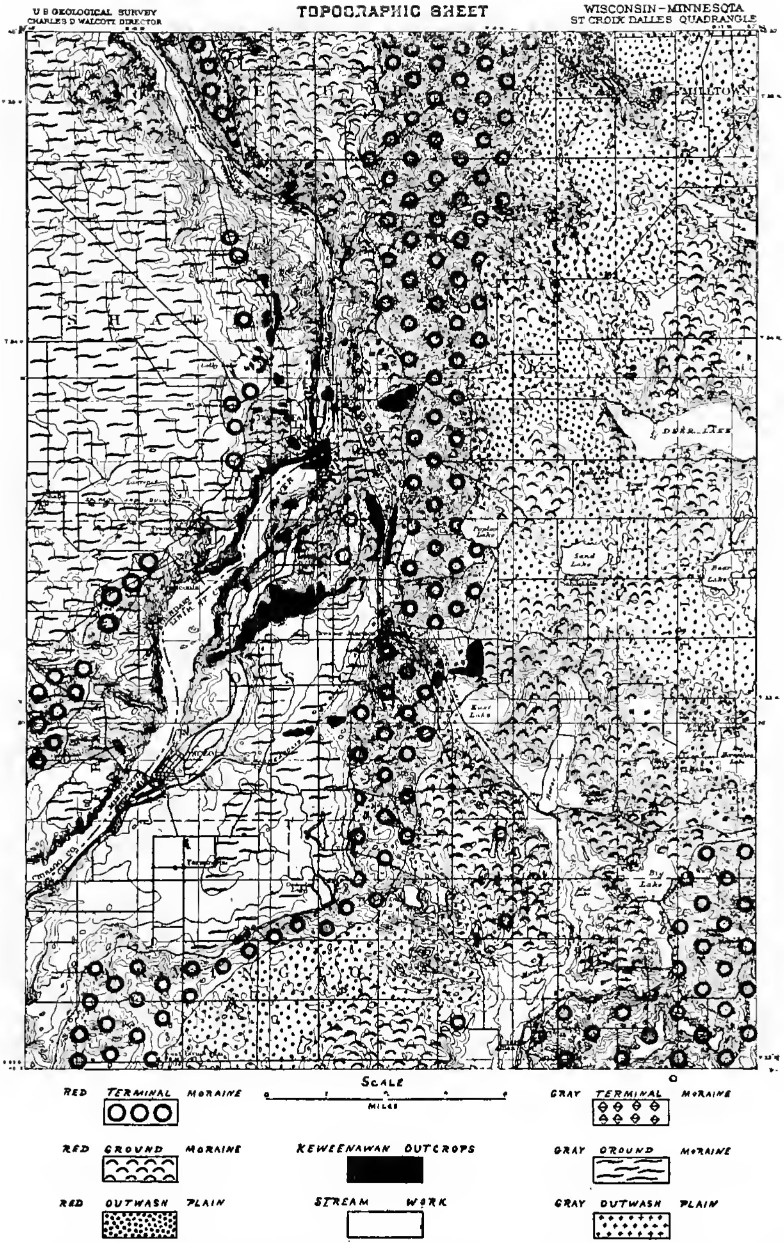


Fig. 31. Map showing the distribution of the glacial deposits around St. Croix Falls. The gray moraines and outwash plains were formed by the Keewatin ice. From R. T. Chamberlin.

material is the Lake Superior region, the reddish sands coming from the Lake Superior Potsdam and Keweenawan sandstones, which are similarly tinted. Some of the red coloring matter was also probably derived from decomposed ferruginous igneous rocks.

"Topography.—In this region the topography, with the exception of postglacial erosion by the river and a few minor streams, is largely the work of the ice of the red drift. In the western part the covering of grey till, and the leveling action of the ice which made it, have modified the original red surface somewhat, though not enough to disguise it effectively; in the eastern portion it remains unaltered, so far as later ice advances are concerned. The most prominent features of this topography are three roughly parallel or concentric terminal morainic ridges which, running northeast and southwest across the quadrangle, mark successive halts in the glacier's retreat. These may be termed in the order of their ages the Alden, St. Croix and Franconia recessional moraines (see map, figure 31). Splendid outwash and pitted-plain topography, especially east of the St. Croix ridge, together with some ground moraine, appear between these morainic belts."

Regarding the advance of the Keewatin sheet he says:

"The Alden moraine runs northeast-southwest just south and east of Big and Rice lakes and then turns north lying 2 miles east of Deer lake, between Balsam lake, Bone lake and Round lake. A few miles to the east lies the outermost ridge of the terminal moraine of the Superior lobe.

"The St. Croix moraine lies just east of and roughly parallel to the St. Croix river; it is very rough and broken and sharply irregular in surface and outline. The eastern face is much more regular than the western, for here the hills and hollows have been masked by the material of the outwash plain filling up the lowland between the St. Croix moraine and the Alden moraine. At Dresser Junction the moraine is broken by a gap indicating the outlet of a lake which formed to the west of the St. Croix moraine; when the ice was stationary at the point marked by the Franconia moraine the waters from its melting was pounded back by the St. Croix moraine and the marginal lake thus formed grew gradually deeper until its surface rose to the top of the lowest portion of the confining moraine; this happened to be in the vicinity of Dresser Junction and the outflow gradually cut down

through the dam draining the lake and leaving a permanent record in the gap.

"The Franconia moraine is the most westerly of the series of moraines and is much broken and obscured by having been passed over by the Red River lobe of the Keewatin ice sheet. It lies almost entirely in Minnesota, but the northern portion enters Wisconsin, crossing the river in the southern part of Eureka township, a few miles north of St. Croix Falls.

"East of Osceola this glacier actually reached the St. Croix moraine; from the north of the map to within 3 miles of St. Croix Falls no grey drift was found on the east side of the river, though striae interpreted as belonging to the grey ice, and a few limestone pebbles indicate that the Keewatin glacier visited these parts. As this region was covered only by the extreme edge of the Minnesota glacier, which seems to have been thin and not to have remained here long, it did not effect a great change in the topography. Some of the hills of red drift were worn down and so many of the depressions filled, but the covering of grey drift is too scanty to mask entirely the old red topography.

"The Gray Terminal Moraine.—While the red terminal moraines in this region are all of the recessional type, though large and prominent, the grey moraine is a limiting terminal moraine marking the extreme extension of the sheet, but it is the weakest and most obscure of all. So far as my knowledge goes, the grey terminal moraine first appears at the north within the quadrangle about half a mile east of the river, and a mile north of St. Croix Falls, where it is very indistinct. North of this, on account of the scarcity of grey drift, it has not been recognized. From this point it runs slightly east of south for 2 miles, becoming a more pronounced ridge; but it cannot be traced beyond the great pit near the railroad tracks, 1 mile southeast of St. Croix Falls station. From the pit the boundary of the grey till sheet swings sharply to the west, and then southwest along the slopes of a high veneered rock hill, until it is lost amid Keweenawan ledges, 2½ miles south of Taylor's Falls. Farther south, however, at Dresser Junction, there is a hummocky ridge, though scarcely more than half a mile long, piled up across the front of the great gap in the St. Croix moraine. This is the best developed portion of the grey moraine. Considering the position of this strip and the direction of the ridge running from St. Croix Falls south to the great pit, it appears a plausible view that the ice front at its maximum point stood along a line connecting these morainic

strips approximately where the railroad is today. However, no grey drift was found on the upper part of the hill to the west, which must have been overridden by the ice according to this view, nor has any direct evidence appeared in support of this idea. A further study will be necessary to establish this portion of the border line. South of Dresser Junction the terminal moraine was discovered only in a single isolated spot, 3 miles southeast of Osceola, where, as is strictly shown in a road-cut, the ice punched against the red St. Croix terminal, leaving the red and grey till in a dovetail contact. That the limit of the grey ice south of Dresser Junction was the western edge of the St. Croix ridge seems probable."

According to Upham the Kewatin glacier followed the Superior glacier by a considerable interval practically as far as the west side of the St. Croix moraine; its outwash passed through the gap at Dresser Junction and overlies the outwash of the St. Croix moraine.

The hard trap rocks which form the sides of the Dalles are marked by numerous "pot holes," which have here a development as great as in almost any part of the world. Pot holes, as explained above (p. 123), must not be confused with the kettle holes of the terminal moraine. The kettle holes are formed by great pieces of ice being buried in the debris of the terminal moraine as the ice was melting away, and so leaving a hole or pit which was previously filled with ice. They are large irregular depressions in the material of terminal moraines. But the pot hole is a deep, near vertical-sided well or cistern in the solid rock, rarely of large diameter and sometimes growing larger below the rim, as a cistern is rounded out. In the bottom are generally found rounded boulders or smaller stones which have evidently been the agent by which the stone was excavated. It is believed that the stones, caught in some eddy or in some accidental depression in the rock, have been swept round and round until they have worn down the solid rock into the shafts or wells called pot holes.

Several types of these pot holes have been made out according to the method of their formation, and it is believed that those of the St. Croix district belong to one of the most interesting of these. Pot holes may be formed either by the action of ordinary streams of great velocity or quieter streams in times of flood, especially near waterfalls or rapids, by the action of subglacial streams, or by the action of Moulins.

A moulin is a vertical tunnel or shaft through the ice of a glacier which has been developed by the melting action of the

warmer surface waters finding its way down some crevasse or smaller crack in the ice until it forms an opening of considerable size down which a stream plunges like water into a wheel pit. Pot holes formed by either of the last two means mentioned above are spoken of as glacial pot holes, to distinguish them from those formed by the action of rivers. The pot holes of the St. Croix Dalles have no evidence of the action of stream erosion around them and it is believed that they owe their action to the presence of moulins, the water plunging down, possibly a great number of feet, through the ice and confined by the ice walls of the shaft, so that it raced around its narrow prison before finding escape through some subglacial channel. The action of the water would be to sweep around in circles the glacial boulders and stones which were swept into the pit from the surface of the ice and soon they would begin to excavate a narrow well which, as shown below, sometimes reached a considerable depth.

Upham, in his description of the region, speaks of these pot holes. (Giant kettles eroded by moulin torrents. Bull. Geol. Soc. Am., Vol. 12.) The pot holes occur on both sides of the river, but are most numerous on the Minnesota side and are especially numerous near the steamboat landing of Taylor's Falls, and for about 50 rods to northward, as between Trap Rock street (the street leading to the landing) and the river. One of the chief areas of the pot holes reaches from the steamboat wharf about 15 rods east-northeast to Angle rock and about 20 rods northward; including large and small there are about 30 pot holes on the area of about one and a half acres. The largest, called by Upham the "caldron," is about 30 feet northeast from the end of the wharf and 50 feet above the river; it is nearly circular at the mouth with the two diameters 25 and 27 feet; the hole is 8 feet deep to the rubbish covering the bottom, which is undoubtedly far below. One hole 13 by 15 feet in diameter was partly cleared from debris and then sounded with long iron rods to a depth of 65 feet below the edge of the hole without even reaching the large boulders which ground out the hole. Another was sounded 85 feet without reaching the bottom; 40 to 50 feet northeast of the large hole called the "caldron" there are two large semi-circular niches in the side of the bluff; these are supposed to be each one half of a pot hole, the other side of which was formed by an ice wall, and when the ice was melted away they remained vertical excavations of the side of the bluff. Because these niches have become covered with brightly colored lichens they are known as the St. Croix fire places.

On the Wisconsin side of the river there is one of these pot

holes about 20 feet northeast of the Sentinel or Old Man of the Dalles. It is 8 feet from the edge of the bluff and is 3 by 4 feet in diameter.

The history of the St. Croix region has been summarized by Upham as follows:—"1. In the Archean time this was a region of heavy lava flows which were even in that time attacked by erosion until they were sculptured into bluffs and crags.

2. The region was next submerged under the Cambrian sea so that it was covered by the sandstone deposited on the bottom of the sea.

3. Subsequent to the deposition an elevation brought the region under the effect of erosion and this was continued for long ages, perhaps even to Cretaceous time, when there seems to have been a second submergence. This last is rather hypothetical; we have no evidence of the transgression of a Cretaceous sea over the state.

4. The region was again raised so that in Tertiary time it was out of water. In this time was formed the valleys of the two rivers now forming the upper and lower St. Croix described above.

5. During the glacial time the present site of the Dalles was perhaps occupied in part by streams, tributaries of the Upper and Lower St. Croix, running in opposite directions but preparing a pair of valleys which, after the diversion of the predecessor of the Upper St. Croix, guided it in excavating the Dalles.

6. The last stage was the partial damming of the Lower St. Croix by delta deposits from tributaries ponding back the waters to form the Lower Lake St. Croix.

Devils Lake, Baraboo* Ridge and the Dells of the Wisconsin.—Rising from the sandy lowland to the south of the Archean highland is the Baraboo ridge sheltering the Devils lake, and near at hand, at Kilbourn City, are the Dells of the Wisconsin. They are not connected in their origin, but their later history is so closely interwoven and their proximity has led to such a close association of the names of these two of the greatest of the beauty spots of the United States that it seems best and not wholly illogical to describe them together. The area does not properly belong in any of the three arbitrary divisions of the state suggested above, but as the Baraboo ridge is an outlying part of the old Archean land and

*So named from Jean Barribaut, a French trapper.

its history is partly that of the ancient peneplain, its study may well follow that of North Central Wisconsin.

Prof. Davis, in his Physical Geography, has outlined the history of the Baraboo ridge and his description may be taken as a good general view before beginning the more detailed study

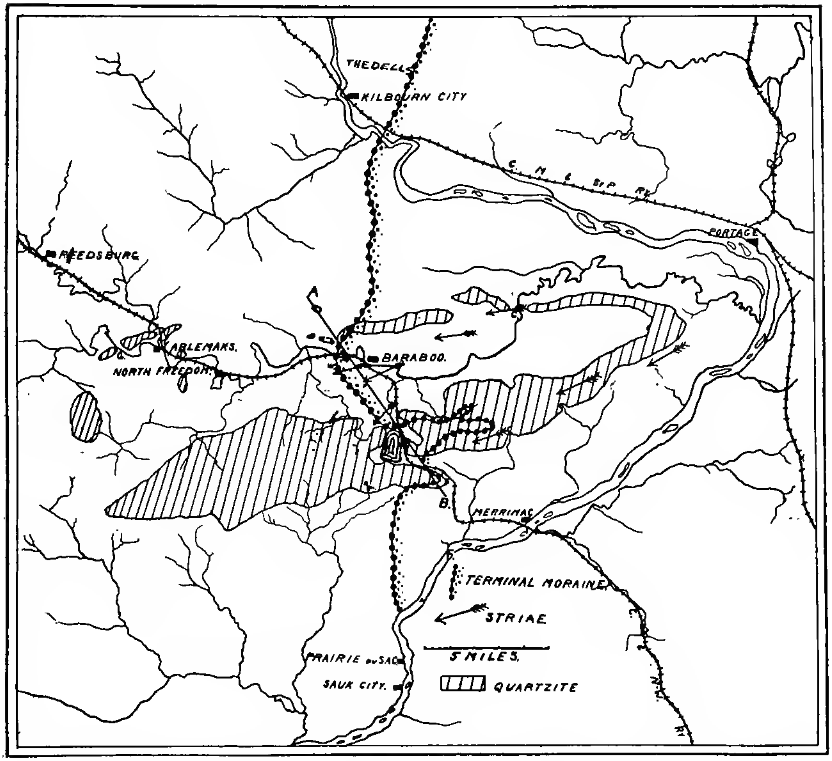


Fig. 32. Sketch map showing the relation of the Baraboo Ridge to the terminal moraine, and the Baraboo and Wisconsin rivers. From Salisbury and Atwood.

of the region. It will be remembered that toward the close of the Archean the surface of the state was reduced to a peneplain, which now appears at the surface in the vicinity of Wausau, but exists far south of that part of the state under

the layer of sandstone which hides it. When the peneplain was produced there were left standing on its surface several monadnocks; one of these, far to the south, was the great residual mass of quartzite now known as the Baraboo ridge. At this stage the

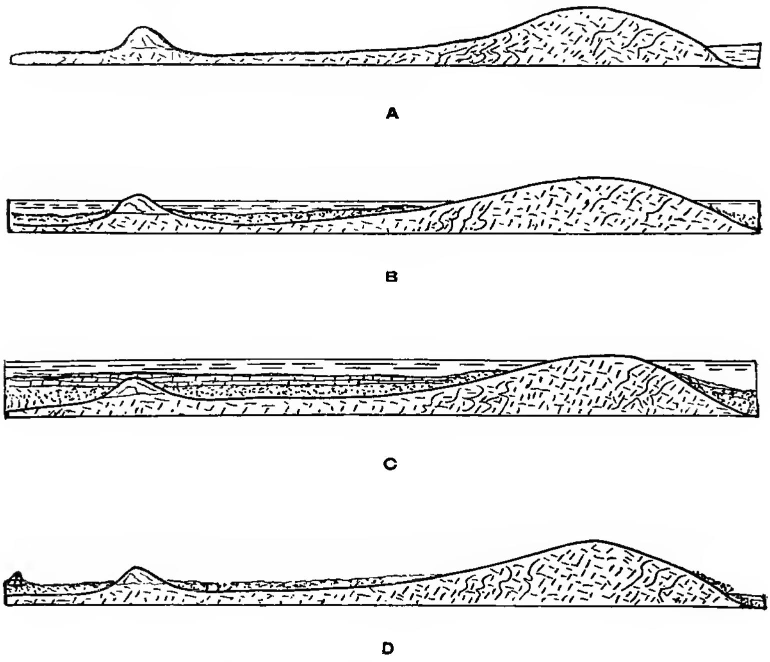


Fig. 33. Diagrams illustrating the history of the Baraboo Ridge. a, The Ridge standing up as a monadnock on the surface of the ancient peneplain; b, The Ridge surrounded by the waters of the Cambrian sea; the top appears as an island and the base is already partly buried in the sandy sediments; c, The Ridge completely buried in the sediments at the bottom of the sea; d, The Ridge partly resurrected by the action of rivers.

state was a great plain with its surface dotted by several hills or low mountain masses. The land was next tipped slowly to the south and the waters of the sea overflowed the land until the

Baraboo ridge was surrounded by water and stood up as an island; gradually the water deepened and the ridge was submerged more and more deeply until it disappeared beneath the surface of the water and finally was buried in the sediments that formed on the bottom of the sea. After a long period the bottom of the ocean was raised and appeared as a great plain, for the ridge was completely buried in the sands and did not show even its summit. As soon as the land emerged it became subject to the attacks of the agents of degradation and the sand was rapidly carried away, the surface of the sand sank under the attack of the degrading forces until the top of the ridge was uncovered and then the sides, until at the present day the ridge stands partly resurrected, rising from the surrounding plain of sand as of old it rose from the waters which had partly engulfed it. The completion of the cycle will come when, in years to come, the sands are completely removed and the ridge will rise as a prominence from a flat plain of igneous rocks, as it did in Archean time.

It may seem that the history thus definitely outlined is fanciful and not susceptible of proof, but the Baraboo ridge has its history written very plainly for those who can read, and below an attempt is made to indicate the steps by which the story has been made out and the evidences of its truth.

The story of the formation of the peneplains and the monadnocks has been outlined on previous pages.

The sands of Cambrian time which now surround the Baraboo ridge* are clean, white grains of quartz cemented together by iron, lime and silica. In many places it lies in thin layers which when separated show the characteristic "ripple marks" produced by the disturbances of shallow water; they are in every particular identical with the similar marks produced in the oceans, lakes and ponds of today when a light wind throws the shallow waters over a sandy bottom into gentle ripples. These sands contain many fossil remains, shells, tests, tracks, borings, etc., such as are found near the shore of modern oceans. The lower layers of the sandstone are of coarser fragments, pebbles, boulderets and even boulders, all of the same material as the solid walls of the Baraboo ridge; these have been consolidated by the cementing process into coarse conglomerates which are easily and typically seen in Parfrey's Glen, on the south

*The subject matter of the following pages is taken largely from the pamphlet by Salisbury and Atwood, The Geography of the Region Around Devils Lake and the Dells. Bull. No. V Geol. Survey of Wis.

side of the south range east of the Notch, in the east bluff of Devils Lake and in the Upper Narrows near Ablemans. All these conditions, the ripple marks, the abundant traces of animal life and the coarse fragments, point to the fact that a beach surrounded the Baraboo ridge in the earliest stages of its partial submergence. Irving made the following statement in regard to these deposits (7 Ann. Rpt. Director U. S. G. S.):—"It is

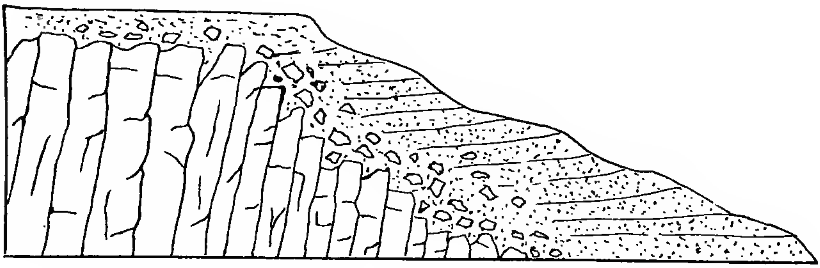


Fig. 34. Sketch showing the contact between the Potsdam sandstone and the Baraboo quartzite bluff. The coarse conglomerate is formed of the boulders formed on the beaches when the Ridge was an island.

doubtful whether anywhere in the world there are to be met with among the ancient formations more admirable reproductions of the conditions which obtain at the present time on every cliffy sea shore than are found in the Baraboo region. A few days' examination of this region enables one to obtain a most vivid mental picture of the conditions which obtained at the time when the sandstone was in process of accumulation. He sees east and west ridges, at times rising into smooth, rounded islets, and again buried some distance beneath the surface of the sea, and all about and against them growing the deposits of the sand washed from them by the waves."

But above the coarse sandstone there are many layers of a finer and cleaner sand, more evenly deposited and free from ripple marks, telling that the shores were now farther distant and that the ridge was buried, for the top of the sandstone, when

restored, is above the top of the ridge and the highest peaks of the sandstone are in places capped with remnants of the Lower Magnesian limestone which once covered the whole region. These limestone layers are strictly conformable with the sandstone layers below, i. e., they lie directly upon and parallel with them, showing that the sedimentation was uninterrupted by any time interval or earth movement of a kind producing a distortion of the rocks. A limestone is formed under special conditions only; its presence, therefore, tells much about the conditions of a region in the time when it was forming. By far the most abundant source of limestone is the coral which, forming into reefs, is broken by the waves and ground into a coral mud, and this mud, settling to the bottom, is hardened into limestone. Corals grow luxuriantly only when the water is: 1. Not less than 68-70 degrees Fahrenheit in temperature; 2. Not over 150 feet deep, and 3. Very clear and free from suspended matter. It is evident then that when the Lower Magnesian limestone was formed over the Baraboo region that there was a warm, shallow, clear sea; the shores must have been far distant or there would have been shore debris. So we have evidence that the Baraboo monadnock was completely submerged, not only beneath the surface of the waters but beneath the sediments in the bottom of the ocean. There were formations higher than the Lower Magnesian limestone deposited over the ridge which have since been removed by erosion, for in Pine Bluff layers of St. Peter's sandstone occur.

The final elevation of the state above the waters of the Paleozoic seas exposed its surface to a period of degradation which, except for the slight deposition during glacial time, has been uninterrupted. During this period the Baraboo ridge has been partly resurrected and again stands above the general surface, but in only a fraction of its original height and proportions.

In its present condition the ridge proper rises from a gently undulating plain with a nearly even surface. Besides the main portion of the Ridge there are several smaller isolated areas of the same material in the vicinity which are evidently lower prominences of the original mass just beginning to be uncovered. The main ridge is commonly described in two parts, the South, or main range, and the smaller North range. The general description given by Salisbury and Atwood affords a very good picture:—"The main range has a general east and west trend and rises with bold and sometimes precipitous slopes 500 to 800 feet above the surroundings. A deep gap three or four miles south of Baraboo divides the main range into an eastern and

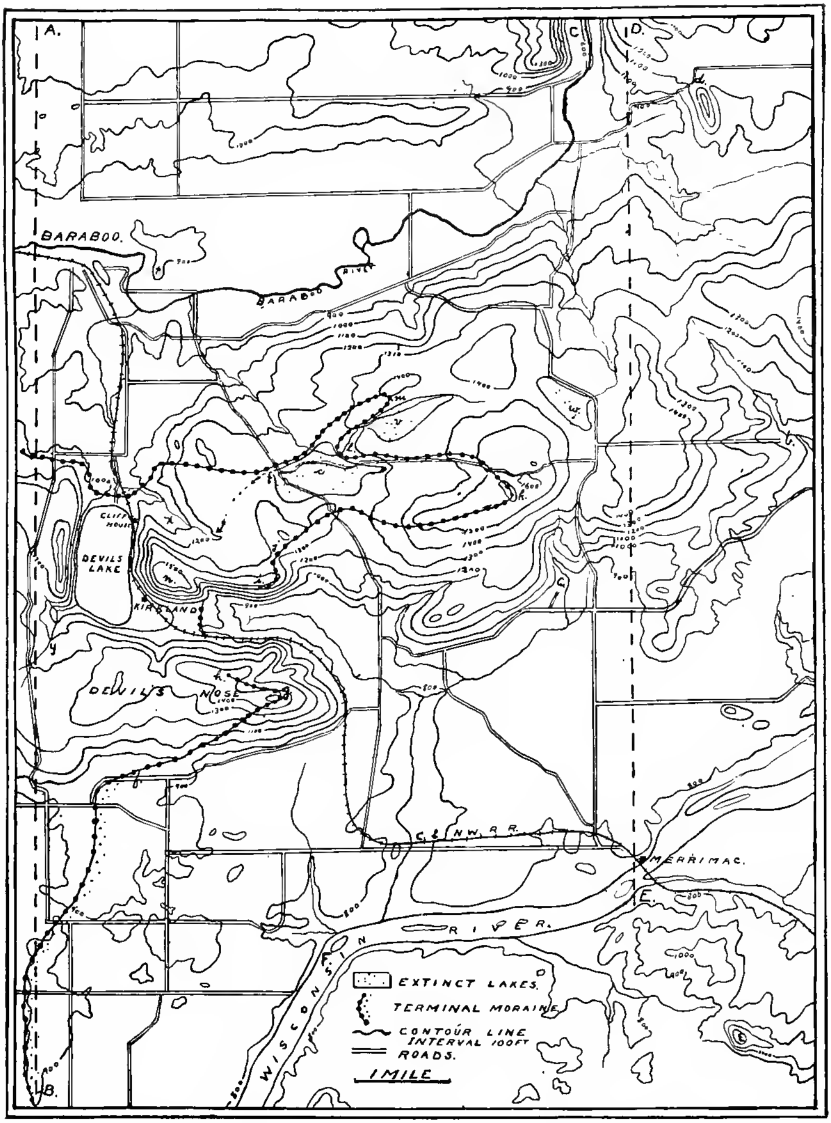


Fig. 35. Contour map of the vicinity of Devils Lake. Contour interval 100 feet. Each contour line connects all points of equal elevation above the sea; crowded contours indicate steep slopes. From Salisbury and Atwood.

western portion known respectively as the East and West Bluffs or Ranges. In the bottom of the gap lies the Devils Lake. * * *

The highest point of the range is about four miles east of the lake and has an elevation of more than 1,600 feet above the sea level, more than 1,000 feet above Lake Michigan and about 800 feet above the Baraboo valley at its northern base. The eastward extension of the west range, lying south of the lake and popularly known as the Devils Nose, reaches an elevation of a little more than 1,500 feet.

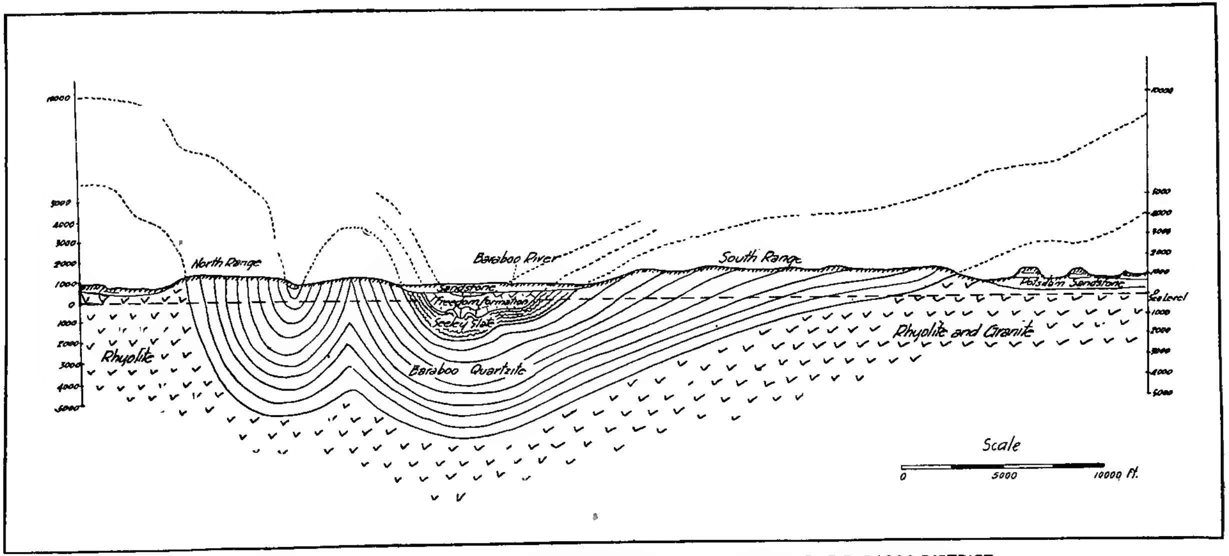
The lesser or North quartzite range rises 300 to 500 feet above its surroundings. It assumes considerable prominence at the Upper and Lower Narrows of the Baraboo. The north range is not only lower than the south, but its slopes are generally less. * * *

About three miles west of Portage the North and South Ranges join and the elevation at the point of union is about 450 feet above the Wisconsin river a few miles east."

The gap in the South Range occupied by the Devils Lake is an old river valley excavated across that part of the monadnock even before it became prominent by the degradation of the surrounding Archean rocks. When the monadnock was submerged the gap was filled with Potsdam sandstone, and in the process of the appearance of the ridge the valley was cleared out by a river which flowed through it. This river was the predecessor of either the Wisconsin or the Baraboo; it has been suggested by Irving that the Wisconsin flowed across both ridges, entering the quartzite area from the north through the gap in the North Range, which is now the Lower narrows of the Baraboo, and out to the south through the gap occupied by the Devils Lake. In this case the Baraboo probably entered the Wisconsin somewhere east of the present city of Baraboo.

The North Range is lower than the South with the crest less even; there are numerous breaks occupied by streams. The most prominent of the breaks is the Lower Narrows, now occupied by the Baraboo river, which has bluffs 500 feet high, and the Upper Narrows, occupied by the Baraboo near Ablemans; the latter is much smaller than the Lower Narrows with lower walls, and was probably excavated by a smaller stream, possibly the predecessor of the Baraboo.

The Iron Ore of the Baraboo District.—The occurrence and value of the Baraboo iron ore has been the subject of an extensive work by the Weidman (Bull. XIII. Geol.



GENERALIZED CROSS SECTION EXTENDING NORTH AND SOUTH ACROSS THE BARABOO DISTRICT.

The horizontal and vertical scales are the same. The Baraboo quartzite rests unconformably upon the basement of igneous rock, consisting of rhyolite, granite, and diorite. The continuous lines represent the synclinal folds of the quartzite, slate, and Freedom formation, upon which rests unconformably the overlying Potsdam sandstone. The dotted lines indicate the probable position of the quartzite, slate, and Freedom formation above the present surface before they were eroded.

Fig. 36. Cross section of the Baraboo Ridge. From Weidman.

Survey of Wisconsin), who discusses its geological relations in great detail.

The ore was first discovered in workable quantities in 1900, although exploration had been carried on from 1887. The mines now producing in any quantity are the Illinois and Sauk mines, a short distance southwest of the town of North Freedom. The work of Weidman has shown that the structure of the Baraboo ranges is somewhat different from that suggested by earlier workers in the region. According to this latest work the quartzite was thrown into folds, of which two predominate, as shown in figure 36. The section of the country shows two great synclines with the eroded crest of an anticline between them, so that the rock dips down from all sides towards the interior basins, which is filled with rock of the later formations up to the Potsdam sandstone of Cambrian time.

"The quartzite of the West Range is thus seen to have a prevailing dip to the eastward, of the South Range to the northward, and of the North Range southward. The dip of the strata is, therefore, with few exceptions, toward the interior valley, and the three ranges taken together form a synclinal basin with a varying amount of arching of the strata within the outer borders of the ranges, the synclinal trough resting unconformably upon igneous rock. (Weidman.)"

Within this basin are rocks of later formations than the quartzite, which have been preserved from the erosion which has removed them beyond the protecting border of the ridges. The general geology of the district is expressed in the following table:—

Pleistocene	Glacial drift.
Unconformity.	Trenton limestone.
Paleozoic sedimentaries.....	St. Peter's sandstone.
Unconformity.	Lower Magnesian limestone.
	Potsdam sandstone.
	Freedom formation (dolomite and iron-bearing rocks).
Pre-Cambrian sedimentaries (Baraboo Series)........	Seeley slate (gray clay slate).
Unconformity.	Baraboo quartzite (quartzite of the Baraboo ranges).
Pre-Cambrian igneous rocks.	

The Potsdam sandstone fills the basin over the Pre-Cambrian sediments and is in turn overlain by the Pleistocene Glacial drift. The Lower Magnesian, St. Peter's and Trenton only appear in isolated prominences left by the general erosion of the country. The Freedom iron-bearing formation is regarded by Weidman as of Middle Huronian or Upper Huronian age.

"The Baraboo iron ore is mainly red hematite with a small amount of hydrated hematite. The ore in its prevailing aspects is more like the hard phases of ore of the old ranges of the Lake Superior district than the soft, hydrated hematite of the Mesabi district. It is believed by the writer (Weidman, Bull. XIII. Geol. Survey Wis.) that on account of the location of the iron ores of this district below the belt of weathering, hydration of the ore will be found to be of slight extent. The ore is usually of Bessemer grade.

The common phases of the ore are soft granular ore, hard banded ore and hard blue ore. The soft granular phases generally carry the highest percentage of iron, the banded and hard blue ore containing usually a larger amount of silica."

It is believed by Weidman that the iron ore deposits of the Baraboo district are the result of the sedimentation of limonite in the form of iron muds in the bottoms of stagnant pools of water rich in iron. At the present day much iron is extracted from the waters of stagnant pools and swamps through the action of minute organisms, both animal and vegetable, and through the action of decaying vegetation; this settles as mud to the bottom and gradually concentrates into a deposit of hydrated oxide of iron, limonite. The limonite, if buried and subjected to the heat generated by the compression and folding of the rocks, may be metamorphosed by dehydration into hematite. Weidman states that the two common theories of iron ore deposition, as "(1) the theory that the iron was originally deposited as ferric hydrate and subsequently merely dehydrated through the process of deep-seated metamorphism; (2) the theory that the ore, as it now occurs, is mainly a secondary alteration or replacement deposit." The second of these is the one ordinarily accepted for the origin of the Lake Superior deposits and has been explained above.

With regard to the size and value of the iron deposits of this district, Weidman says:—"The chances for finding iron ore in this district are probably as good as the chances have been in other districts. An iron-bearing member like the Freedom formation, with a thickness of 400 to 600 feet, may reasonably be expected to contain a number of ore deposits. From five to ten

million tons of ore, at least, have been located, and it seems reasonable to believe that the district will become as important as some of the iron ore districts about Lake Superior."

The Kettle Moraine and Its Effects in the Vicinity of Baraboo Ridge.—Inspection of the map, figure 35, will show that the great terminal moraine, and so the edge of the ice in the last Wisconsin epoch, occupied a rather peculiar position in the vicinity of the Baraboo Ridge. In general it passes through the center of the region, dividing it between the driftless and the drift covered regions on a line approximately from Kilbourn City to Prairie du Sac. As the moraine enters on the north it passes about two miles east of Kilbourn City, thence a little west of south to about two miles west of the city of Baraboo, and then across the Baraboo Ridge, but in crossing the Ridge it executes a remarkably sharp detour to the east, so that it crosses the north end of the Notch and passes about three miles east on the slopes and summit of the East range, and then recurving blocks the south end of the Notch and lies on the summit of the east end of the West range, the Devils Nose. The course of the moraine in this region is responsible for a series of changes during glacial times which resulted in the development of two of the most delightful scenic features of the state, the Devils Lake and the Dells.

Devils Lake.—In preglacial time the Notch was occupied by a river of about the size of the present Wisconsin, the peculiar course of the moraine crossing the course of this river twice as it passes over the South Range cut off a considerable portion of the valley, which was then partly filled with water from the melting ice. The immediate postglacial level of the lake was very much higher than the present level, for deposits from floating ice are found on the sides of the valley 90 feet above the water; how much higher the water rose is not known. Devils Lake is, in short, a portion of an old abandoned river course cut off from the rest of the valley by morainal dams. On the north the lake is separated by the width of the moraine only, from the headwaters of a tributary of the Baraboo and on the south by no greater amount from the headwaters of a stream which flows south into the Wisconsin. Well drillings in the Notch north and south of the lake show that the Archean rock is covered to a considerable depth with the glacial material.

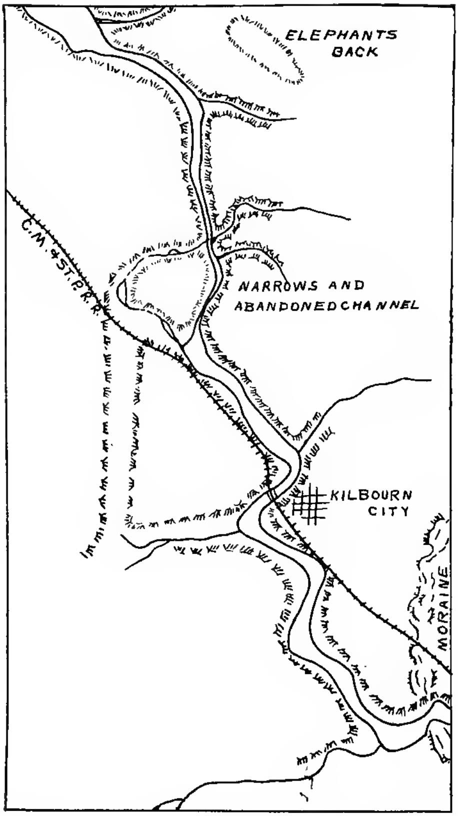


Fig. 37. Sketch map of the vicinity of the Dells, showing the abandoned channel and the Narrows. After Salisbury and Atwood.

The Dells.—Near Kilbourn City the Wisconsin river was forced out of its course by the moraine; above the city it flows in a well-developed preglacial valley wide and deep, but close to the city it was compelled to abandon its old channel and seek a new one across the sandstone. Swollen by the waters of the melting ice the river was both swift and of large volume. The sandstone is soft and a steep, sharp-sided valley was speed-

ily cut out which has become known as the Dells of the Wisconsin. Even in postglacial time the river has again changed a portion of its course and left a readable record of its action; the middle portion of the Dells, known as the Narrows, is narrower and with steeper sides, if possible, than the rest of the gorge, it is younger in all of its features.. To one side of the Narrows can still be traced the abandoned portion of the channel in a series of swamps and lakes through which water still flows in time of high flood (fig. 37). This old channel was the original continuation of the main channel, but the river for some cause was deflected for a short distance and then returned to the old channel; this deflected portion is of course younger and forms the Narrows.

The peculiar forms assumed by the rocks in the Dells and the picturesque lateral gorges, as the Witches' Gulch, Artists' Glen, etc., which add so much to the beauty of the region, are due in large measure to the peculiar structure and lines of weakness in the rock, which directed the erosive forces and at the same time permit them to act more vigorously. Van Hise has explained the development of the erosion forms and the direction of the courses of the tributary streams as the result of a series of "joint planes" which pass through the sandstone. (Trans. Wis. Acad. Sc., 1895.)

Joints or joint planes are lines of breakage which extend through the sedimentary rocks more or less vertically, but always approximately at right angles to the strata; they are generally in groups and are roughly parallel to each other. Sometimes there are several such groups crossing each other at different angles, but the members of each group are distinguished by their parallelism. The cause of such breaks across the layers is not definitely known, but it is supposed to be due to a twisting strain in the rocks caused by the elevation of one corner of a considerable mass of horizontal rocks. Joints are decided lines of weakness in the rock, for as they extend down across the layers they afford paths by which the water, frost and other eroding agents can most easily penetrate the mass and destroy its coherence. Should a small stream or river flowing across such a country come in contact with one of the joint planes it would be much easier for it to cut down its channel along the line of weakness formed by the weathering and it would thus be guided in working out its course.

Van Hise describes the formation of the Dells as follows:— "The south slope of the state is a gently plunging anticline with a north and south axis near the center of the state, and undoubt-

edly with minor folds attendant. The folding of the rocks into anticlines and synclines was accompanied by jointing in several sets, forming a rectangular system. The main joints run in a general east-west and north-south direction, with a possible set in a third direction. There is much variation in the direction, so that for short distances the joints do not follow the main direction of the system. The attendant gorges of the Dalles, formed by small streams entering the Wisconsin at this point, are developed along systems of joints, so that in following the course of one of the small gorges the course shifts from east-west to north-south and back to east-west again as the stream which developed the gorge followed one or the other set of joints. The turnings of the main streams are accompanied by the entrance of smaller tributaries on another set of joints. Many of the lateral streams end in cols (narrow, shallow depressions on the summits of the divides); the gorges may be traced from where they have a depth of from 15 to 50 feet to where they are extremely shallow and pass, sometimes very suddenly, into a mere seam, which is the continuation of the joint which determined the stream's course.

In the large streams the rectangular turns are disguised by the erosion at the turn rounding the angle, but in the smaller ones where erosion has been less prominent the right angled topography is very prominent. The development of the streams on the line of joints has made their down-cutting very rapid, so that they have soon reached the level of the Wisconsin river, the local base level, and have begun to widen their valleys; this has resulted in the production of lateral openings of the second order, or isolated rocks of queer form and other of the scenic features characteristic of the Dells. Taylor's Glen, Artists' Glen, Witches' Gulch and Coldwater Canyon are lateral gorges which have reached this stage."

The Narrows themselves are possibly due to the development of two streams along joint planes until their headwaters met.—"Thus the Narrows, in rocks no harder than those confining the rest of the course of the Wisconsin in the vicinity, are explained, and we have the unusual phenomenon of a strong river in a gorge abandoning its course to follow another gorge made by two small, weak tributary streams which had no advantage in slope."

Steamboat Rock and similar detached rocks were formed in the same way as the Narrows, but on a smaller scale, and the process has gone farther.

The Camp Douglas Plain.—Just west of the Baraboo Ridge the valleys and hillsides tell the story of two stages of degradation almost as complete as that of Archean time. The same stages of degradation extended into southwestern Wisconsin, but they are somewhat more plainly told just here. The earlier of the two peneplains is traceable in a series of level hilltops and ridges about 500 feet below the present level of the Baraboo Ridge; the peneplanization was never completed at this stage, for, though the rivers had all cut down their bottoms to the local base level and had begun to widen their valleys on this level, there were considerable blocks of land standing between the valleys, much as in the Wausau region described

The Great Plain at Camp Douglas with Masses of Residual Sandstone Rising from it. Photo by Bennett.

above. When the land had reached this stage of dissection the farther degradation was arrested by an uplift; the rivers regained their velocity, were rejuvenated, by the increase of the slope and began to cut down again in the bottoms of their valleys. The down-cutting has progressed so far that the second peneplain is already indicated, for on the flats of the Baraboo and Wisconsin rivers, about 800 feet below the top of the Ridge, the rivers and their tributaries have ceased to lower their beds rapidly and are spreading out over wide and flat bottom lands. The completion of this peneplain was arrested by the accession of the glacial time with its deposits.

The second peneplain may be traced up the valley of the Baraboo for some distance and thence up the valley of the Lemonweir until beyond New Lisbon it opens out into the wide flats surrounding Camp Douglas and Necedah. Here we have, in the language of Salisbury and Atwood, "the best example of a base-leveled plain known." The land is low and flat and sandy, extending for a long distance without a change of level. In isolated patches over the area rise vertical sided residual masses of sandstone which have been sculptured by the weather into fantastic forms determined by their composition and structure. These are monadnocks as truly as the Baraboo Ridge, but they are formed of the same material as the sandstone plain from which they rise and are preserved because of the accidental greater hardness of their upper layers. A single residual mass of quartzite identical in origin and history with the Baraboo Ridge stands in the northeastern portion of the plain just south of Necedah. The residual masses of sandstone vary in size from more than a mile to only a few feet in diameter and show all stages of degradation in their differing heights; the very presence of the slender shafts and towers of small diameter tell that this portion of the land is within the driftless area where the ice never penetrated. The different rocks have received local names, as Friendship Rock and Roche a Cris near Friendship, Elephant Rock near Kilbourn City, Target Bluff and Beleaguered Castle near Camp Douglas, etc. None of the rocks reach a greater height than 200 or 300 feet above the adjacent plain, but in their different development they indicate that originally the tops of all were on the same level, and it has been suggested that this is due to the presence of an older peneplain, perhaps the one indicated by the higher levels along the Wisconsin and Baraboo rivers.

An entirely different interpretation has been put upon the plain around Camp Douglas and Necedah and its extension down to Baraboo by Weidman. His investigations show that the plain is composed of loose sandy deposits reaching a depth of more than 250 feet in places before the solid sandstone is reached. Wells penetrating this loose layer strike the sandstone below at very different levels, showing how irregular is the true surface of the sandstone and how different from a true peneplain. He explains the plain as built up by the rivers upon the old eroded surface. Originally the ground was higher and the rivers cut deeply into the land; then the land sank and the rivers filled up their valleys with flood-plain material and even deposited material over the surrounding uplands. Now the land is again elevated and the streams are down-cutting again.

Smith (Water Power of Northern Wisconsin, Water Supply and Irrigation Paper No. 156) describes the course of the Wisconsin river as follows:—"The headwaters of the Wisconsin river are found in an intricate network of lakes and swamps occupying the plateau region near the northern boundary. Its extreme source is found in the Lake Vieux Desert, a body of water about ten miles square on the line separating the northern peninsula of Michigan from Wisconsin, at about 1,650 feet above sea level. The general course of the river for the first 300 miles is south. At a point near Portage it turns abruptly westward, and in the next 100 miles flows nearly west, joining the Mississippi river at Prairie du Chien, only 40 miles from the southern boundary of the state.

The drainage basin includes 12,280 square miles, with an average width of 50 miles and a length of 225 miles.

Because of its long traverse from the extreme northern to the extreme southwestern part of Wisconsin the topography of the basin includes nearly every form found in the state. Like the upper Chippewa valley, the northern half is a densely wooded region of hard and soft timber except where cleared for farming. The woods gradually give way to a semi-prairie region with a gently undulating surface, but with occasional decided ridges both of rock and glacial origin. A very striking surface feature toward the southern part is found in the "Baraboo quartzite" ranges, which have an elevation of from 400 to 700 feet above the surrounding country. These ranges comprise two main ridges from four to six miles apart, extending nearly east and west in the section of country west of Portage for about 25 miles, but uniting and ending abruptly on the west side of the valley near Portage. The angle of the river at this point seems due to its effort to secure a passage around this rock barrier.

Through a portion of the city of Portage and southward the river can hardly be said to have an eastern divide. Fox river approaches within 1½ miles of the Wisconsin at this point, only a low marsh intervening. Even this marsh has a slope of three feet toward the Fox river. At the present time levees at this and other points prevent the Wisconsin at times of high water from overflowing into the Fox river. These levees for a distance of several miles compel the river to flow along the contour instead of in the direction of the maximum slope. The reasons for this and other peculiarities of its valley are interestingly discussed in the Geology of Wisconsin (Vol. 3).

It is evident that such an uncertain divide as this cannot have formed one of the original permanent features of the drainage of

the region, but as the disposition of the surface soil is due to glacial action, modified by subsequent erosion and transportation, this may be fairly attributed to such a cause. The rampart of limestone which compels the lower Wisconsin to flow west does not stop south of Portage, but continues east and north, although less prominent, forming an eastern barrier to the flow of the Wolf river. The course of the upper Fox to Lake Winnebago is sluggish, consisting largely of marshes and lake-like expansions. On account of the depression of the divide at Portage, the continuation of the southern barrier northeast, the same slope of the upper Fox, the large trough of the Wisconsin below Portage, which it is unable to occupy, while above the river is more nearly in proportion to its channel of drainage, and finally the evidently modern outlet for the Wolf and the upper Fox through the lower Fox—the conclusion is reasonable, if not inevitable, that at one time the Lake Winnebago system drained southwest into the Mississippi and the Wolf was the true continuation of the Wisconsin above Portage, while the present upper Wisconsin was merely a tributary of the main stream."

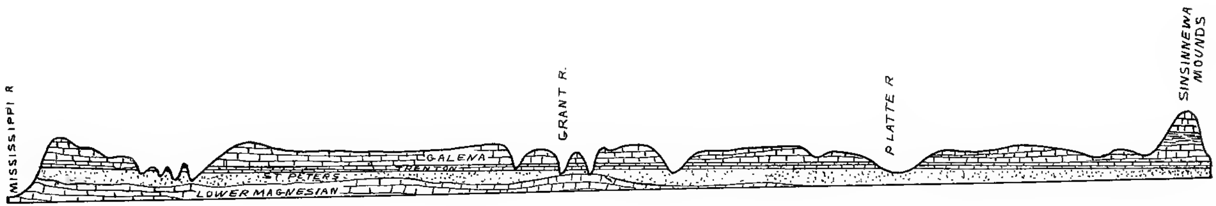
CHAPTER VIII.

SOUTHWESTERN WISCONSIN.

The southwestern portion of the state owes its claim to recognition as a distinct physiographic area to two very fundamental facts: 1. As explained in the description of the structure of the state, the rocks lie nearly horizontal, one upon the other, in an orderly sequence of deposition, and so differ from the contorted and metamorphosed rocks of the North Central region and the tilted rocks of the Eastern region. 2. It lies almost entirely within the driftless area and so was never visited by the ice and bears none of its marks.

A pretty comprehensive view of the main features of this portion of the state can be obtained from the summit of the Military Ridge along the right of way of the Northwestern Railroad from Madison west to Fenimore, in Grant county. Nearly equally good views can be had from the train on the Lancaster branch or on the Galena branch north of Cuba City, in the southeastern part of Grant county. So seen, the land is easily recognized as a table land tipping slightly to the southward and deeply incised by the streams, whose valleys separate the land into distinct blocks and discontinuous ridges. The tops of the hills and ridges are close to a common level, indicating the former existence of a continuous flat surface.

The Military Ridge.—The dominant feature of the region is the great Military Ridge which runs west from Madison 16 miles to the Blue Mounds, thence southwest about 15 miles to the neighborhood of Dodgeville and so west to the Mississippi near the mouth of the Wisconsin, a total length of about 85 miles. It runs parallel to the Wisconsin river and about 15 miles south of it on the average, with an average elevation of about 600 feet above Lake Michigan, but the Blue Mounds located on its surface reach a height of 1,151 feet above Lake Michigan. Beginning in the town of Wingville, Iowa county, a branch from the ridge may be traced southeast through Iowa



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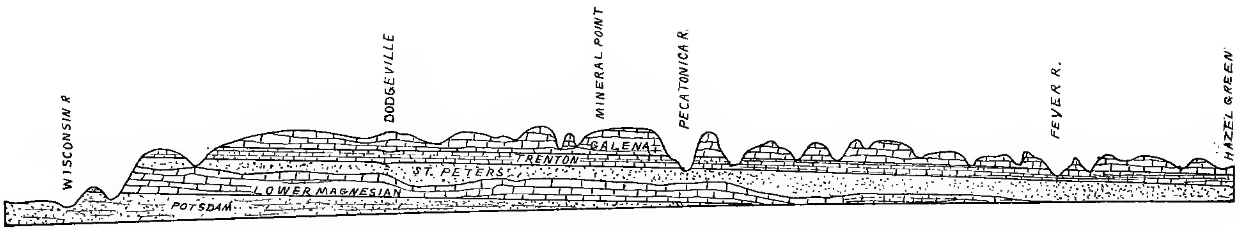

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Fig. 38. Cross section of the state from the Mississippi to the state line. Vertical scale: 1 inch = 1,600 feet.

Fig. 39. Cross section of the state from the Wisconsin river to Hazel Green. Vertical scale: 1 inch = 1,200 feet.

and Lafayette counties, forming the divide between the Platte and the Pecatonica rivers. The most conspicuous feature of this portion of the ridge are the Platte Mounds in the northwestern corner of Lafayette county; they are about 700 feet above Lake Michigan, but stand well up above the surrounding surface. A less perfectly developed section of the ridge may be traced south from the Blue Mounds through Dane and Green counties, separating the waters of the East Pecatonica from those of the Sugar river.

The Rivers. — The relation of the Wisconsin river to the Military Ridge is much the same as the relation of the Fox river and the upper portion of the Rock river to the cuesta ridges of Eastern Wisconsin. From the north the river flows over the soft sandstone in southerly direction until it comes in contact with the ridge, when it turns and flows parallel to its northern face almost directly west to the Mississippi. The rocks are almost horizontal, but have a slight dip to the south, so that the lateral migration of the stream is down through the dip of the strata to the south, as explained upon page 34. The face of the ridge to the north is determined by the outcrop of the hard Lower Magnesian limestone and the bed of the river is cut in the soft underlying sandstone of the lowland. The wall of the river valley is the steep face of the first cuesta ridge and the north bank is flat and low, showing that the river has gradually shifted to the south, following the dip of the strata, slight as it is. North of the river there are many hills capped with the same layers that crop out in the face of the bluff on the south, so it is evident that the river has not shifted from the north clear across the lowland to its present position, but, guided by some condition no longer traceable, ran across the hard limestone until it broke through the capping layer and then began to shift to the south.

The crest of the ridge forms a sharp divide between the streams flowing north into the Wisconsin, and the Sugar, Platte and Pecatonica rivers, which flow south. The streams flowing north are relatively short and very steep, having a fall of approximately 100 feet in the first quarter of a mile; they are in consequence actively cutting streams which have worn down their valleys into steep-sided gorges, dividing the steep slope between deep valleys and projecting headlands, so that it has a rough and in places even mountainous appearance. The streams flowing into the Wisconsin from the north have a very different appearance, for they flow over flat bottom lands with slow current and do little cutting.

The streams flowing south from the crest of the Military Ridge over the gentle southern slope have a more sluggish course, with muddy bottoms; the valleys are deep and wide, and the bluff side is rather the exception. The smaller tributaries have greater velocity and steeper valley sides near their source, but as they approach the main stream they become more gentle in slope, with sluggish current and more muddy water.

Grant, in his description of the Lead and Zinc Region of Southwestern Wisconsin (Bull. IX, Geol. Survey of Wis.), has described these valleys in the following words: "Each valley is a sag with gently sloping, convex sides, which merge gradually into the general surface of the plain. Lower down, toward the mouth of the stream, the valley floor has a steeper slope and the sides are steeper also, but have still a gradual slope. Farther down still, the narrow valley widens out, has a less marked slope, and acquires a rather wide, flat bottom. These flat bottomed valleys are characteristic of all the larger streams and many of the smaller ones also. At times the valley is bounded by steep slopes or cliffs and the cliffs are commonly of Trenton limestone. Sometimes they are of Galena limestone, and, much less commonly, of St. Peters sandstone. A good example of these sandstone cliffs may be seen just west of Mineral Point, where the St. Peters is more consolidated than usual. The bottoms of the valleys are from 100 to 400 feet, in places more, below the general level of the district, and continuous slopes of 200 feet in altitude are common along the valley side."

Mention has been made above of the fact that the country south of the Military Ridge is marked by the evenness of the hill tops and the suggestion has been made that this evenness of the sky line indicates the presence of a former peneplain; perhaps one of the peneplains indicated in the region west of the Baraboo Ridge. When this level was first noticed it was considered that it was continuous with the peneplain in the north, which has been described in the region around Wausau, but Weidman has shown that the two are entirely distinct both in time and position, the one on the north having been tilted so that it passes under the one to the south at a low angle (p. 110). There is little certainty that the level south of the Military Ridge is a peneplain at all. A glance at the geological map will show that the top layer is the Trenton limestone; this was directly overlain by the soft, easily eroded Cincinnati shales, and it is altogether possible that the general even surface is due to the fact that the soft shales have been removed, exposing the even upper surface of the limestone as it was formed by deposition.

Kummel has called attention to the rivers of this region in relation to the possible peneplain, explaining their condition as follows: At the close of the erosion cycle which formed the plain the rivers were running in "wide, flat valleys, with broad flood plains, in which they meandered freely. In the case of the Fever river especially the meanders are preserved very perfectly. In some cases the neck between opposite sides is very narrow (as near the town of Benton). In the larger streams an equally well preserved series of open and close meander curves with rock spurs between the curves 100 to 200 feet high, duplicate on a large scale the smaller meanders of the stream on the flood plain of the valley." It is evident that these large curves were produced when the streams were flowing slowly with many windings on the flat surface of the peneplain, but that later the land was elevated and the streams, gaining an increased velocity, thereby have cut down into the land, excavating deep valleys, which, however, preserve the curves of the stream before the rejuvenation.

The history of the region is summarized by Kummel as: (1) Country almost completely base-leveled. (2) A few monadnocks left on the surface of the peneplain. (3) The region uplifted and the rivers rejuvenated. (4) The rivers have again cut down almost to their grade.

Grant says (Bull. IX, Geol. Survey of Wis.):

"The present topography of the district is due to subaerial erosion acting on approximately horizontal strata. The general history of the erosion may be summed up as follows: After the deposition of the Niagara limestone there is no absolute proof that other and later formations were deposited. If such were deposited they have been entirely removed by erosion, and of such earlier erosion we have no certain records. There is, however, one period of erosion which has left marked records, and this is the period in which the land stood in a position long enough for the streams to reduce the whole district to a nearly level region or peneplain. The peneplain is now represented by the level uplands already described. The only parts of the district which were not reduced to the general level were the mounds, which rise as monadnocks above the peneplain. The date of the formation of this peneplain is not known, but it may be Tertiary age, and if so, is thus later than the possibly Cretaceous peneplain, which is exhibited farther north in Wisconsin. After this peneplain was formed the land was again elevated, and erosion again began its work cutting into the surface and forming the present valleys. This elevation took place before

the Glacial time, and there is some evidence to show that at one time during this period of erosion the land stood at a somewhat higher level than at present. Since the revival of erosion a large portion of the district has been lowered and the region is now in a stage where the streams are not so rapidly deepening their valleys as the valleys are widening. The district has passed through the stage of the most marked relief and has entered on the stage when future erosion will serve to subdue rather than accentuate the present differences of topography. The district may thus be said to be intermediate between maturity and old age, although much nearer to the former than the latter."

The remarks are equally applicable to the region whether the original plain is a true peneplain or one due the preservation of the surface of the hard Trenton limestone.

The Mounds of Southwestern Wisconsin.—These are most important elements in the scenery of Wisconsin and are of the utmost importance to the physiographer as monuments telling the early history in the formation of the state and the degradation it has suffered. In the discussion of this portion of Wisconsin just completed, it has been shown that the land was worn down from some former elevation almost to a level, but that there were left certain residual masses, monadnocks, on its surface, and that afterwards the land was elevated and the rejuvenated rivers began to cut down again. It is the monadnocks rising from the old peneplain (?) which form the mounds. It will be seen at once what an important position they hold, for they are remnants of a former level persisting through a second cycle of erosion. They had the same relation to the rivers which formed the plain as the blocks of land between the present rivers, Sugar, Platte and Pecatonica, have to those rivers, but rather more, in proportion, of their mass has been removed.

The Blue Mounds standing near the line between Dane and Lafayette counties are the largest and the best known. The larger, West Mound, is separated from the smaller, East Mound, by about a mile and a half. They rise from a general level surface formed on the Trenton limestone, and the Galena limestone and the Cincinnati shales show in their sides. The capping layer is Niagara limestone, the same which forms the outer cuesta ridge in the eastern part of the state, but here it is a very hard and siliceous, almost quartzitic stone, stained brown with iron. It is the local hardness of this stone which has preserved it from destruction to act as a roof protecting the softer rocks below. It is a most fortunate circumstance for us that the stone has

here resisted the weathering so long, persisting to show how, at some former time the Niagara limestone, as well as the formations beneath it, extended clear across the state. Were it not for these few isolated patches we should have no knowledge that the Niagara limestone extended any considerable distance farther west than the present face of the outer cuesta.

The Platte Mounds in Lafayette county are three in number; they have the same form, structure and origin as the Blue Mounds, but the hard capping layer has been broken through on the easternmost and has almost disappeared, exposing the Cincinnati shales, and the top is under cultivation.

The Sinsinawa Mound of Grant county is in all respects of history and structure similar to the others. Numerous less prominent and less well known mounds occur scattered throughout the southwestern counties.

Springs are very common in this part of the state at the junction of the St. Peters sandstone and the Galena limestone. Notable are the springs on the side of the Blue Mounds only 150 feet below the top. The position of these springs far up on the sides of the mounds has been attributed to various causes, as thermal and hydrostatic pressure, but it is unnecessary to seek such explanation, for the flow from them is at no time greater than might be expected from the size and capacity of the collecting area above the level of the spring.

In several places in the vicinity of the mounds there are sink holes in the limestones opening into more or less good sized cavities below; these tell of the action of the underground waters in dissolving the rocks and forming channels which are the first steps in the development of caves. The sinks are of various sizes, from 5 feet across to one 50 feet across and 20 feet deep, which is the largest observed. They occur generally in linear arrangement, showing that the solvent waters are working along lines of weakness in the limestone. Most of them occur in the Trenton limestone, but some are found even in the capping layer of Niagara limestone on the summits of the mounds.

Artesian wells are very abundant in Southwestern Wisconsin, but only a few examples of the flow can be given. In Sparta the well borings go down 300 feet through the Potsdam sandstone to the Archean and have an abundant flow, rising several feet above the surface. At Tomah and La Crosse wells are sunk through the sand to the Archean rocks; at Tomah the water failed to rise to the surface of the ground. At Prairie du Chien a well sunk 59 feet, according to the First Survey, struck several water bearing layers in the sandstone and finally stopped at

the Archean; the water rose 60 feet above the surface of the hill upon which the well was located and about 100 feet above the level of the Mississippi.

The Lead and Zinc Deposits (Grant, Bull. IX, Wisconsin Geol. Survey). — The lead and zinc occurs in the Galena limestone and in places in the Trenton below. The Trenton limestone in this region is from 40 to 100 feet in thickness and is a very pure calcium carbonate. The different layers have received local names, as the buff limestone, the blue limestone, the brown rock, the green rock, and the glass rock. The last forms the upper layer of the Trenton; it is a "very fine grained, very compact limestone, which breaks with a conchoidal fracture and which when fresh is of a light brown or chocolate color. On exposure to the air, however, this color changes to a bluish grey." The Normal School and the High School at Platteville are built of this stone.

The Galena limestone is a "granular, crystalline, porous, and at times sandy (i. e., limestone sand and not quartz sand) rock, which by weathering is reduced to irregular and ragged outlines. Its color is a light yellowish grey, sometimes buff, but when it has not been exposed to weathering and when found below the water level it is usually of a light bluish grey color." * * * "In composition the Galena limestone is a dolomite ($Ca\,Mg\,(CO_3)_2$ instead of $Ca\,CO_3$, and it thus differs markedly from the underlying Trenton." In many parts of the country it is impossible to separate the Trenton from the Galena, but within the Wisconsin area they are separated by a thin stratum of somewhat carbonaceous shale called Oil Rock. "This oil rock is a compact, very finely laminated, soft shale, which varies in color from a very light yellowish grey to a dark brown chocolate color, and even becomes perfectly black in places. The dark brown chocolate color is the customary one. It contains a considerable percentage of carbonaceous material, which is evidenced sometimes by the peculiar petroleum odor which the rock gives off, especially when heated. When dry, particles of this rock will usually burn with a thick smoky flame."

It is believed that the ores of lead and zinc (principally Galenite, PbS, and Sphalerite, ZnS), occur widely scattered through the Trenton and Galena limestone, but in very small quantity; it has been stated by Grant that in the Potosi district, where the ores are most easily estimated, that they comprise only "one-fourteenth of one per cent, or a little more than seven millionths part of the rock. * * *" This amount seems ab-

surdly small at the first glance to be reckoned as a source of all the lead and zinc that exists in the region, but it must be remembered that the present deposits which seem so rich are concentrations in a small space of the ores which were originally scattered very widely. The concentration of the ores has been accomplished by the action of the underground waters, which in their movements to and fro have gathered up the minerals and transported them to some locality favorable for their deposition. Exactly how this has been accomplished is not certain and has been the cause of much speculation and investigation. * * *" The Galena limestone lies between the shale at the upper limit of the Trenton and the Cincinnati shales above and they dip somewhat to the south, with the north end exposed; it is seen

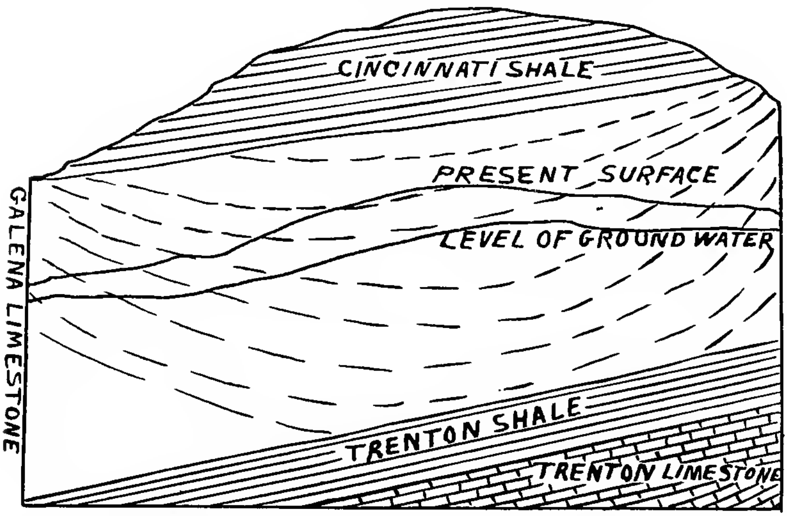


Fig. 40. Diagram illustrating the concentration of the lead and zinc ores in southwestern Wisconsin. The broken lines indicate the direction of flowage of underground water. After Grant.

that in the preceding ages, before the Cincinnati shale had been removed, that the conditions were favorable for the development of artesian waters, i. e., the water that entered the limestone in the north and gradually flowed down the dip between

the two impervious layers would soon come to be under hydrostatic pressure which would force it upward through any crack or opening that might happen to be present; this would insure a circulation of water from below upward through the strata. Later, when the Cincinnati shales were removed by erosion and the land was deeply trenched by the rivers, there would be a strong movement of the waters downward. It is believed by Van Hise and others that the upward movement of the water gathered together and raised toward the upper portion of the Galena considerable quantities of the lead and zinc sulphides and then when the downward movement commenced these ores already deposited were gradually concentrated in the cavities of the rocks.

Those who are especially interested in the story of the formation of the ores will find valuable accounts in Vol. II of the First Geol. Survey of Wisconsin. In Bull. IX, The Lead and Zinc Deposits. Second Geol. Survey by Grant, and in Monograph XLVII of the U. S. Geol. Survey, A Treatise on Metamorphism, by Van Hise.

The deposits occur in three general ways: (1) In crevices. (2) In "honey comb" deposits. (3) Disseminated through the rock.

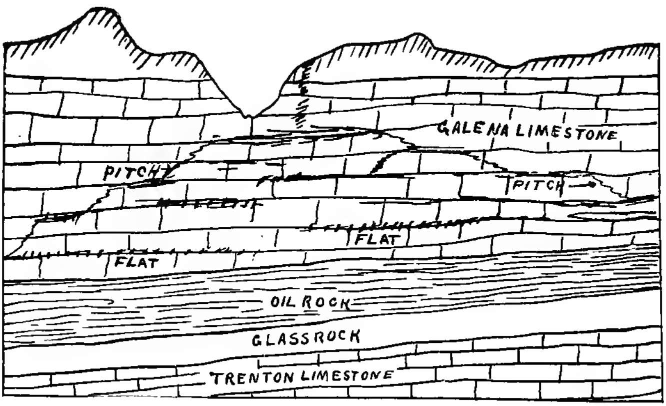


Fig. 41. Diagramatic cross section of the lead and zinc regions of the upper Mississippi valley. Showing occurrence of the lead and zinc ore in "flats and pitches." After Van Hise, Leith and Smyth.

When the region was first worked the deposits were almost entirely taken from the crevices and openings in the rocks. These were largely the result of the solution of the limestone by the circulating waters and followed in a general way the stratification, so that they would open horizontally between the strata for a distance and then break across to another layer almost at right angles to the strata (compare fig. 41); such openings were referred to as the "flats and pitches." The region was originally worked for the lead, and the zinc was hardly recognized; as the workings were carried more and more deeply it became increasingly difficult to control the water in the mines until, as the water table or level of underground water was reached, together with the fall in price of zinc and other causes, the mines were worked less vigorously. As late as 1902 mining was again resumed and has progressed with unabated vigor ever since. As now conducted the mining operations are largely below the water level and directed almost entirely to the recovery of the zinc.

CHAPTER IX.

EASTERN WISCONSIN.

Eastern Wisconsin is distinguished as a separate physiographic region by the fact that the rocks are tilted to the east, lying shingle-wise on the old Archean mass to the west and north, by being covered by the later drift and by its peculiar climatic conditions influenced by Lake Michigan. Most of the features due to the two first conditions have been explained on the preceding pages, as the development of the alternate cuesta ridges and lowlands, the course of the Fox and Rock rivers, and the position of Green Bay and the Lake Winnebago, and somewhat of the position and character of the morainal deposits. There remains to be described, however, one of the most characteristic results of the glacial deposits, the peculiar drainage of the region. It is the glacial streams and lakes of Southeastern Wisconsin which have made it celebrated for its beauty and have added so much materially to the state in the location of summer homes, estates and pleasure resorts on the borders of the larger bodies of water.

In Bulletin VIII of the Geological Survey of the State, Lakes of Southeastern Wisconsin, Fenneman has given an accurate and detailed account of the lakes, from which much of the following material is taken. According to him the lake basins originated in five different ways:

"1. Pits due to the melting out of blocks of ice.

"2. Erosion valleys blocked by drift.

"3. Valleys between terminal moraines.

"4. Troughs of small glacial lobes.

"5. Undulations in the ground moraine."

The lakes of the first class may have been formed in one of several ways:

1. The basins may have been formed by masses of buried ice which were left behind when the ice front was melting back;

as the moraines accumulated detached masses of ice were buried deeply under layers of debris and melted only very slowly, while they finally melted the debris fell into the cavities left by the ice and the deep, sharp-sided pits in the morainal ridges. Such are the kettle holes, which are only occasionally filled with water.

2. Floating icebergs in terminal lakes may have grounded and been buried in lake deposits; the subsequent melting would result in pits.

3. When the ice is in retreat the stoppage of the free flow of water due to marginal wastage of the glacier may cause deposits of more or less stratified material; in this way may be buried masses of ice which are so laden with subglacial debris that it cannot float and in melting this would form pits. Lakes

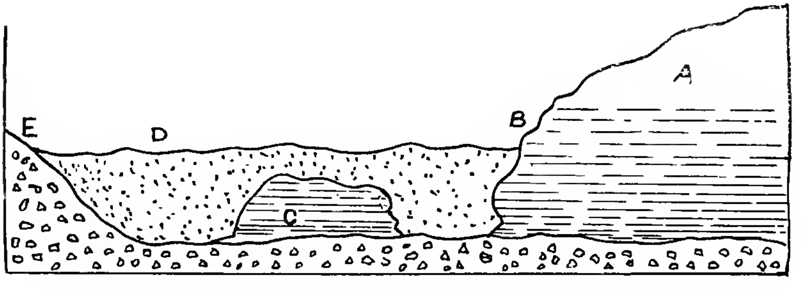


Fig. 42. Diagram showing the origin of lake basins by buried blocks of ice. a, clear ice; b, lower part of ice filled with debris; c, a block of ice from the lower part of the glacier, so filled with debris that it cannot float and buried in d, gravel from the surface of the glacier; e, an obstruction to the drainage from the glacier. From Fenneman.

of this last kind are always characterized by the steep slope of the sides, their position on glacial plains, and by the irregularly deposited glacial material of their banks.

The most important lakes of this first class are the Oconomowoc group and the Lauderdale-Beulah group.

Lakes of the second class are quite common; many of the preglacial valleys were so shallow that they were completely filled by the deposits, but others were deeper and were partly ob-

scured, and some valleys were even deepened by the erosive action of the ice. Such valleys might be partly or completely stopped by local deposits of debris, which would act as a dam to the water of the river flowing in the valley and cause the for-

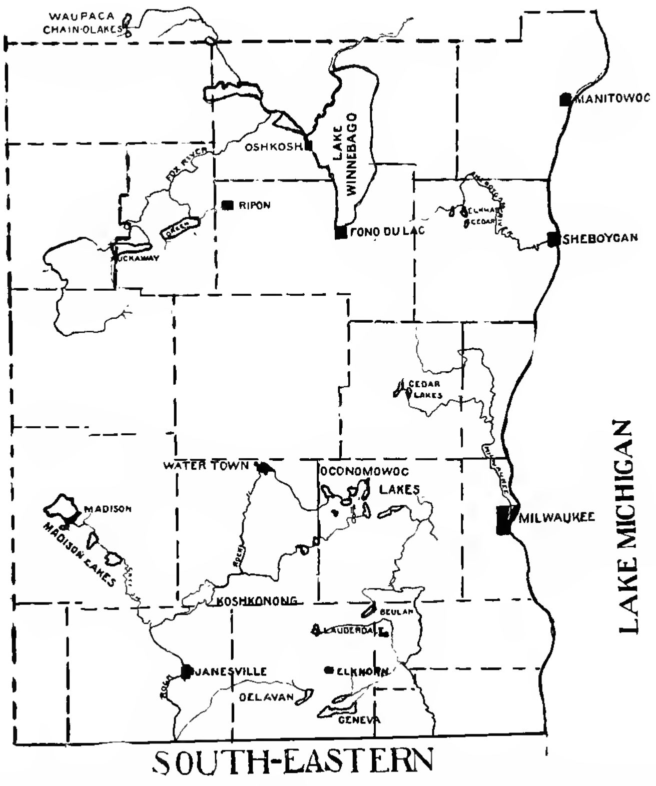


Fig. 43. Map of southeastern Wisconsin showing the location of the most important lakes. From Fenneman.

mation of a lake. Such lakes are recognized in the field by: "(1) There must be a valley in the subadjacent formation itself, and not merely in the drift. This valley may show itself in rock cliffs, as on Green and Mendota lakes, or it may be known by

exposures near the lake, as at Pewaukee, or it might become known only in the drilling of wells (as in the preglacial Troy valley described by Alden). If the material in which the former valley was cut be of an unconsolidated nature, as an older drift sheet, the determination is much more difficult, though not necessarily impossible. (2) There must be a dam of glacial drift. This dam may be either of terminal or ground moraine. Lake Mendota is held by a dam of terminal moraine, while the divisions between the other lakes of the chain on the Catfish river are rather inequalities of the ground moraine. (3) The surrounding slopes show in general a ground moraine topography. * * * (4) There is frequently a line of lakes along the former valley, as the Green-Puckaway line and the line along the Catfish river. This is not always present; Pewaukee lake, for example, is alone. Neither can it be said that the lakes are always elongated in the direction of the former valley; Monona, for example, is elongated in another direction, and Lake Kegonsa is nearly circular. But whether by a series of lakes or the elongation of one, or the mere continuation of the valley, the course of the preglacial valley can be fairly ascertained in all such cases in the area studied. (5) When the depth of the valley has been increased by scooping, the products of the scooping may appear in the drift to leeward. It may also appear in this case that the bottom of the lake lies deeper than the bed rock under any portion of its rim; in other words, that there would be a basin in the bed rock if the drift were removed, a condition that could not be brought about by the mere damming of an erosion valley."

In this class belong the Madison lakes, the Waupaca chain of lakes, Green and Puckaway lakes, and Pewaukee lake. The position of the Madison lakes in the old river valley is indicated by their former names, Kegonsa was First lake; Waubesa, Second lake; Monona, Third lake, and Mendota, Fourth lake. During preglacial times a valley ran southwest from the vicinity of Madison and drained its waters into the Wisconsin, and one ran southeast from the same locality, occupied by the precursor of the Rock river. These streams together formed the long valley reaching from Janesville to the Wisconsin river by way of Madison. At their inception these streams began their work on the surface of the Trenton and Niagara limestone anywhere from 600 to 1200 feet above the level of Madison and by the glacial time had cut through the limestone and were running in channels excavated in the Potsdam sandstone from 50 to 100 feet below the present level of the Catfish river. During the glacial time the stream running into the Wisconsin was nearly obliterated

by the ice, its lower portion was filled with debris, and the terminal moraine lay across the channel; the result was that its course was reversed and the drainage of its basin diverted into the Rock. The upper portion of the stream's course was broken into a series of basins by the irregularities of the ground moraine, which now form the Madison lakes.

Lakes Mendota and Monona were possibly deepened by the erosive action of the ice, for they are deeper than the others; they are elongate in the direction of the ice movement and they have piles of sandy material on their south sides, such as would have been accumulated by the shoving of the ice. Lakes Waubesa and Kegonsa are much shallower and have no elongation parallel to the motion of the ice.

The Waupaca Chain of Lakes consists of nine lakes about 40 miles northwest of Winnebago. They are the result of the clogging of the channel of an old pre-glacial valley which followed somewhat the same course as the present Waupaca river. Rainbow lake is the largest.

Pewaukee lake occupies the channel of a stream which formerly flowed to the west to join the preglacial Rock river. The valley was carved deeply in the Niagara limestone, which formed a rather prominent escarpment on its south shore; this now appears at Rocky Point on Pewaukee Lake. The ice in its passage down the valley perhaps deepened it, but left deposits at the point which is now the west end of the lake, forming a dam and converting the stream into a lake.

The region around Green lake is marked with great ridges and intervening valleys, which were formed almost entirely by river erosion before the glacial time, for the walls of the valleys are limestone and sandstone, instead of glacial material. The drift over the ridges is thin and the ice did not do a great deal of erosion, but it did deposit enough material to obstruct the channels and impound the waters, forming lakes. Green lake occupies one such trough and is separated from Puckaway lake, which occupies a continuation of the same trough, by a mass of glacial debris. Twin lakes and Spring lake occupy similar, but smaller valleys.

Green lake has an area of 11½ square miles and is 237 feet deep. The depth of the water and the height of the surrounding shores, with their overshadowing forests, give to the water the tinge which suggested its name.

The third class is thus characterized by Fenneman: "That portion of the kettle moraine which was formed between the

Michigan and the Green Bay glaciers has at places a number of nearly parallel ridges. When basins are enclosed between such ridges they may be distinguished from those of other classes named by very definite marks: (1) The ridges themselves must be recognized as terminal moraine. The topography of the slopes thus has an expression which is distinctive, at least from classes 1, 2, and 5. (2) Such lakes have their length in the direction of the terminal moraine. The depth of the drift on their border must be such as to exclude them from class 2, though it may easily happen that the line of the terminal moraine may agree for some distance with that of preglacial erosion. This is probably true of the moraine around Big Cedar lake, which is the best example of the class.

It should be observed that even in this example there was another factor concerned in the origin of the basin. While the main features are those of a trough between two ridges of terminal moraine, it is quite probable that but for the presence of ice blocks, the outwash from the glaciers would have entirely filled the trough with gravel, as it partly filled it by a gravel train on the west side.

To this class belong Elkhart lake, in Sheboygan county, and Big and Little Cedar and Silver lakes, in Washington county. Elkhart lake lies on the gentle slope of the Niagara cuesta, a few miles east of Lake Winnebago. The Cedar lakes lie somewhat to the south, in Washington county, but occupy the same position upon the Niagara cuesta.

The lakes in troughs of small glacial lobes are distinguished as follows: "(1) Their length is in the direction of the ice movement. (2) They have the terminal moraine on their lee end; it may be also for some distance back along their sides. (3) They cannot be accounted for as stream valleys, though it is probable that such lobes would be located on drainage lines rather than on divides. This is the class of lakes which they most resemble. They must be distinguished from them by the absence of a rock valley at the level of the lake. For example, in the case of Lake Geneva, the drift is very thick. Whatever drainage valley far below may have determined the glacial lobe, the lake is held probably 100 feet higher than it would have been by the damming of any valley cut in the subadjacent rock." Lakes Geneva, Delavan and Como are good examples of this class. The origin of these lakes is described in detail by Alden (The Delavan Lobe of the Lake Michigan Glacier. Professional Paper No. 34, U. S. Geol. Survey). The formation of the terminal moraine of the Delavan lobe has already been described. The Elkhorn moraine

is but one ridge of the whole terminal moraine, marking a stage in the retreat of the glacier.

Origin of Lake Geneva and Lake Como.—"With the retreat of the glacier to the Elkhorn moraine is to be associated the origin of Lake Geneva, one of the most beautiful of Wisconsin's many lakes. This lake, situated in southern Walworth county, is nearly 8 miles in length; its width varies from one-half mile to 2 miles, and the bottom of the trough in which it lies is 200 to 400 feet below the crests of the Elkhorn moraine on the north, the Darien moraine on the south, and the ridge, supposed to be the extension of Marengo Ridge, on the west. At the east the trough is more open, yet, instead of deepening toward the outlet, the lake gradually shallows in this direction. The lake reaches its greatest depth, 142 feet, in the western part, between Camp Collie and Cook's Camp. At the foot of the lake there is but a few feet of water. It is very evident that the basin was not produced by post-glacial erosion.

"The mode of its formation appears to be this: The earlier glacier of the Wisconsin stage, which formed Marengo Ridge, moved westward down the preglacial Geneva valley to its junction with Troy valley. During the advance the valley afforded a line of discharge for the glacial waters, which flowed southward through Troy valley. When the advance ceased Marengo Ridge was formed as a terminal moraine. This drift dam blocked the outlet of the valley, but where it crossed the preglacial depression there was a considerable sag in its crest. Through this sag much water from the final melting of this glacier escaped, and this trenched the drift dam and kept the valley open. The tributary valley in which lies Lake Como discharged its waters into Geneva valley by way of Williams bay. It is not improbable that these valleys afforded the principal outlet for the glacial waters of western Kenosha, southern Racine, and southeastern Walworth counties, until the ice front had retreated 25 to 35 miles to the eastward.

"During the late Wisconsin invasion the ice of the Delavan lobe advanced southward across Geneva valley and formed the Genoa and Darien moraines, the latter of which again blocked the outlet of Geneva valley, at the same time leaving that part of the valley within the moraine unfilled with drift. There is a sag in the crest of the Darien moraine opposite the head of the lake, but its elevation, 1,000 feet above the sea, is so much greater than that of the Nippersink outlet at Genoa Junction that the westward discharge of the waters was not resumed on the with-

drawal of the ice front to the Elkhorn moraine. The valley thus remains closed by a 280-foot dam of drift. When the Elkhorn moraine was formed the valley occupied by Lake Como was cut off by the morainal deposit between the heads of Lake Como and Williams bay, and the last of the drift composing the bulky ridge to the east was deposited.

"The south slope of the ridge north of Lake Geneva, on which the ice front rested for a time, shows considerably more erosion than does the north slope of the same ridge; this was not improbably due to the discharge of the glacial waters into the lake basin. Probably, also, more or less material was washed into Williams bay at this time, and at the foot of the lake the gravel terrace on which the village of Geneva stands was formed. The remarkable thing, however, is that the basin did not receive more filling than it did. The ice must have continued longer in the basin than on the neighboring ridges, so that a filling of ice may have prevented any considerable filling with drift until the ice front abandoned the crest on the north. The disappearance of the ice from the White River and Como valleys left the lakes in their present conditions, excepting that the level of Lake Geneva is now maintained by an artificial dam."

The Origin of Delavan Lake.—"The elevated tract between this lake basin and Lake Geneva is regarded as probably due to the burial of the northwestward extension of the Marengo Ridge. During the early Wisconsin glacial invasion, while the glacial front stood at the Marengo Ridge as a terminal moraine, the water from the melting ice would be discharged into the lower area to the northwest and west, and would flow off thence to the south through Troy valley. If the valley north of the site of the lake was largely blocked with drift, the waters would be confined to a distinct channel bordering the moraine, where they would scour out rather than make any considerable deposits. Considerable water may also have come from the northeast, near the morainal front along the line of Jackson Creek valley, the northeastward extension of the lake basin.

"When the later invasion of the Wisconsin stage took place the Delavan glacial lobe advanced over this area, deposited the Darien moraine transversely across whatever filling of older drift there may have been in Troy valley, across the supposed northward extension of the Marengo Ridge and the intervening trough, and was melted back to the Elkhorn moraine without entirely obliterating the earlier drift features. The damming of the valley by the deposition of the Darien moraine inclosed the basin.

"As in the case of Lake Geneva, a long finger of ice probably continued in the basin after the ice had disappeared from the higher areas on either side. That this really is the case there is indication in the peculiar location of the little valley just south of the lake. The position of the little valley, which was probably developed by the glacial waters when the ice front stood at the Elkhorn moraine, looks as though a mass of ice lying in the basin had held a stream halfway up the gentle slope to the southeast and forced it to cut a channel there. As the ice melted, the waters in the basin overflowed at the lowest point and there developed the present outlet.

"While these hypothesis of the origin of these three lakes are not without objections, they at least afford fairly satisfactory explanations of how the basins may have been formed under the conditions afforded by the several glacial advances and retreats."

The last class of lakes, those formed in undulations of the ground moraine, are less easily designated than the others. "To this class must be referred a large number of basins whose conditions of formation cannot be more definitely given. They are: (1) Shallow, since the curves of the ground moraine are gentle when no other conditions are present. (2) Agreeing with these gentle slopes under their waters, the slopes of their shores are likewise smooth. This type grades into type 2, as the reason for the inequality becomes more apparently due to erosion valleys in the preglacial surface." A good example of this type of lake basin is Turtle lake.

The Rivers of Southeastern Wisconsin.— These are peculiar in their tendency to run for considerable distances parallel to the shore of the lake before finally entering it; this is especially true of the Milwaukee river, the Root river, which enters at Racine, and the Pike river, which enters at Kenosha. It is notable that the northern stretches of these streams lie parallel to low ridges of morainal material. The mouths of all of these streams were blocked by bars before river improvement cleared the channels. There is a notable tendency for sand and drift to gather on the north side of all piers and breakwaters which are built out from the shore in this region; this is evidence of a current or series of currents in the lake parallel to the shore and the geologists of the First Survey suggested that it was the growth of bars formed by currents, across the mouth of the rivers which had gradually shifted the position of the opening until the rivers had come to run parallel to the shore for some distance. Compare the description of the formation of the Chequamegon bar.

Later work by Leverett (The Illinois Glacial Lobe. Monograph 38, U. S. G. S.) and by Alden (The Delavan Lobe of the Lake Michigan Glacier. Professional Paper No. 34, U. S. G. S.) show that the course of these rivers is determined rather by a system of low moraines of retrocession lying between the great terminal moraine and the lake than as suggested in the First Survey. The last stage of the ice in the formation of the terminal moraine is locally referred to as the Valparaiso stage. Alden has described the system of low moraines of retrocession as follows:

"As already noted, the Valparaiso morainic system is bordered on the east by a distinctively ground-moraine tract. East of this, in Milwaukee county, eastern Waukesha county and the eastern halves of Racine and Kenosha counties, there is a series of broad, gentle ridges of drift which nearly parallel the shore of Lake Michigan. Mr. Leverett in his studies found these same ridges continuing southward into Cook county, Ill., between the Valparaiso moraine and the lake shore. Similarly located ridges of drift were found in northwestern Indiana and southern Michigan, which were thought to belong to the same series. This system of ridges, which appears to mark further stages in the retreat of the Lake Michigan Glacier, has been designated by Mr. Leverett the 'lake-border morainic system.'" The distribution of these ridges in Wisconsin is shown in figure 44. "While in a large part of this extent the ridges are clearly marked and distinctly separated, so as to give the peculiar north-south trend to the drainage lines, they are cut through at intervals by the streams, and in some places contiguous ridges are coalescent, so that there may be some difference of opinion as to their exact correlation. This is, however, of little moment so long as the distinctive features of the topography are recognized.

It has been stated that when the front of the Delavan lobe reached the Valparaiso moraine in its retreat the lobe had almost disappeared. During these subsequent stages, however, there was enough lobation of the margin to give a marked westward shift to these lake-border ridges in Milwaukee county. This westward shift amounts to six or seven miles, so that new ridges appear to the east, in northern Milwaukee and in Ozaukee counties, which have no correlatives at the south (Fig. 44), or their southward continuations are to be found beneath the waters of Lake Michigan.

In general the topography of this lake-border belt differs but little from an ordinary ground-moraine area. Here and there groups of kettle holes pit the surface, and in some places considerable deposits of gravel occur, but for the most part the sur-

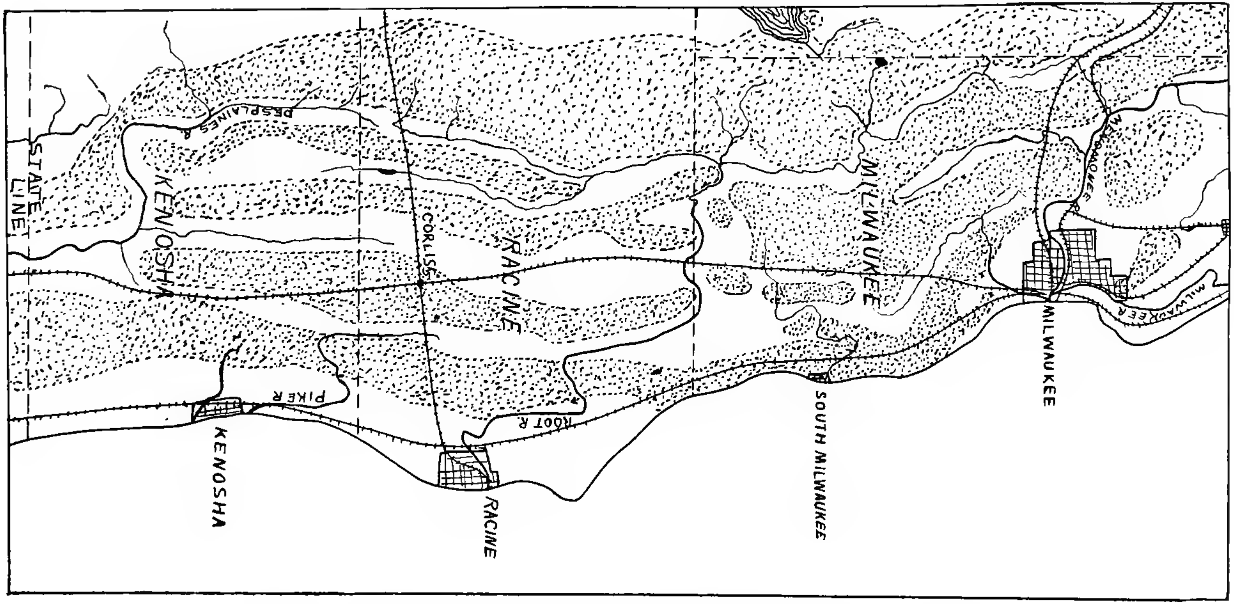


Fig. 44. Sketch map of the southeastern part of the state, showing the low moraines of retrocession between the terminal moraine and Lake Michigan and the relation of the rivers to the moraines. From Alden.

face is marked by broad, gentle undulation. The notable feature of the tract is the disposition of the drift in broad ridges parallel to the lake shore, so that, though the general elevation decreases toward the east, the drainage reaches the lake only where the streams have cut transversely across the trend of the ridges, as in the case of Root and Pike rivers. One of the streams, Desplaines river, in Illinois, in fact does not enter the lake, but flows southward to Illinois river. Milwaukee river flows more than 30 miles between ridges of this lake-border system before it enters the lake at Milwaukee, though through most of this distance its course is within three miles of the lake, and at some points the shore is less than one mile distant. These ridges vary in width from one to four miles, and generally have longer east slopes and shorter west slopes, so that the elevations of the crests are successively lower on passing eastward to the lake. The crest of the west ridge stands 220 to 360 feet above Lake Michigan. The middle belt is marked by two more or less distinct crests, one of which is again subdivided.

The most sharply defined of these ridges south of Milwaukee is that lying nearest the lake shore. This ridge is continuous 25 or more miles southward, to Winnetka, Ill., where it is intersected by the lake shore. The crest of this ridge is 120 to 140 feet above the lake. It is thus 50 to 60 feet lower than the higher crest of the middle belt, and about 120 feet lower than that of the west ridge. The reliefs on the west sides of these ridges range from 20 to 60 feet, and on the east from 60 to 180 feet. The thicknesses of the drift penetrated by wells range from a few feet, where some buried rock ridges occur, to 300 or more feet where there are pre-Glacial valleys beneath. The bulk of the drift appears to be till, but extensive stratified beds are exposed in the lake-bluff section of the east ridge.

While the front of the Lake Michigan Glacier stood at the west ridge of the lake-border morainic system in Waukesha and Racine counties, the water from the melting ice was ponded over the low areas to the west or flowed directly to Fox river. The outflow evidently was not vigorous, as no outwash deposits have been found. Muskego and Wind lakes and the surrounding marshes are evidently the remnants of an extensive shallow lake formed at the time.

On the withdrawal of the Lake Michigan Glacier from the Valparaiso moraine in Illinois, Indiana and Michigan a marginal lake was formed by the waters accumulating between the inner slope of the moraine and the retreating ice front. From Kenosha county southward the water discharged from the ice front, as it

stood at the west ridge of the lake-border morainic system, flowed southward to this lake.

When the ice margin withdrew to the middle belt the flow of the glacial waters to Fox river ceased entirely. Thenceforward all the water from the melting glacier in the area under discussion went southward to this glacial lake by the valleys between these ridges. The final withdrawal of the ice front from the east ridge of this series allowed the expanding lake to reach southeastern Wisconsin, substituting lacustrine for glacial conditions in the eastern part of this area.

In the vicinity of Waterloo, in Jefferson county, there are several outcrops of quartzite very similar to those of the Baraboo Ridge. They lie in a broad erosion basin of St. Peter's sandstone drained by the Crawfish river. The outcrops appear in four groups and from each of the groups a train of quartzite boulders detached by the glaciers is distinguishable for several miles to the south in the drift. At Waterloo the quartzite appears as a series of low polished domes, roches moutonnees; the first and most important is at Rocky Island, near the junction of the Crawfish river and Waterloo creek; the successive domes to the south cover an area of two miles long by three-quarters of a mile wide. At Hubbleton, one and one-half miles to the east, is a series of knobs parallel to the Waterloo outcrops. Near Lake Mills there is a single outcrop in the east half of Lake Mills township, and at Mud lake, west of Lake Mills, there are several low swells of the quartzite appearing above the surface. They have practically the same history as the Baraboo Ridge, but are much less conspicuous and were probably of much less height originally. In fact, all over the eastern part of the inner lowland and of Southeastern Wisconsin isolated masses of igneous and metamorphic rock break through the upper layers to remind us how closely the igneous rock lies to the surface.

The southwestern part of Eastern Wisconsin is celebrated for the large number and perfect development of the drumlins which are scattered over its surface; they are especially numerous in Dane and Jefferson counties, but extend into Walworth county, and a few examples are found in Waukesha and Racine counties. Isolated drumlins are found north and east of these counties, but in small number, and grow less numerous farther from the terminal moraine. Their probable origin has already been discussed.

Drumlins occur most plentifully in Dane and Jefferson counties near Waterloo, Sun Prairie and Jefferson. Here the hills

are generally elliptical in outline, with their long axis running parallel to the direction of the striae on the rock surface, from northeast to southwest. The slope of the sides is gentle and the hills do not rise to an elevation of more than 160 feet above the surrounding country, and even this is exceptional, all heights from 20 to 160 feet being recorded. The form of the ellipse is quite regular, but in the majority of cases it can be seen that the northeast end is somewhat broader than the southwest and the end is also usually higher and the slope somewhat steeper than the other. It will be seen, then, that the long axis lie parallel to the direction of the ice motion and that the higher and steeper ends lie in the direction from which the ice came. The land surrounding the drumlins is low and in many cases swampy; the streams and roads are guided in their directions by the drumlins as they twist and turn to avoid the irregularly placed hills.

On the northern and western edges of the drumlin region are found many hills that resemble the drumlins in outward form and are hence called drumlinoidal, but which are not true drumlins, having a notably different origin and structure. So closely do they resemble the true drumlins that it is impossible to detect their true nature unless an artificial or natural section reveals their structure. These hills are referred to by Chamberlin as "veneered hills." Where a mass of rocks projecting through the mantle of drift catches the drift in the bottom of the glacier and holds it back until a considerable quantity is accumulated, enough to cover completely the original mass, the mass so accumulated is given the form of a drumlin by the forward movement of the ice over it. Such a hill would have a core of solid rock, but it might be so deeply buried that only accident would reveal its presence.

At Madison the elevations known as Capitol Hill, University

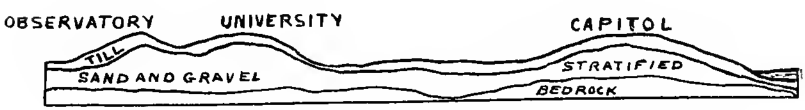


Fig. 45. Section of the drumlins at Madison. From Upham.

Hill and Langdon Hill are drumlinoidal in form and general structure, but according to Upham (The Madison Type of Drumlins. Am. Geol., Vol. XIII) they are composed of a mass of stratified drift overlain by a veneer of till from 5 to 10 feet in thickness. He advances the theory that they are masses of

material accumulated by waters from the surface of the ice plunging down into great crevasses in the edge of the ice as it was breaking up in its final retreat and that the masses so accumulated would, of course, be roughly stratified. They were later covered by a layer of unstratified glacial material from the surface of the ice in the complete melting.

CHAPTER X.

THE CLIMATE OF WISCONSIN.

Climate is usually defined as the sum of the weather of a region or as the sum of the temperature and rainfall. The climate of the state is determined by its latitude and distance above the sea level primarily, but it is greatly influenced by the presence of the two great lakes which form its eastern and northern boundaries in large part.

The rainfall is derived almost entirely from the cyclonic disturbances or storms* which pass across the United States at more or less regular intervals and in a more or less direct path from the west to the east; it is the uncertainty of the time of passage and the intensity of these storms which lends to the countries of the temperate zones the element of irregularity in sunshine and rain which constitutes no small element in their adaptation to the life of an energetic and progressive people. If the air in its movements were undisturbed by the passage of these storms the wind would blow across the state uninterruptedly from the west, or a little south of west, to the east, but as a storm drifts across the country the winds are drawn into it from all sides, passing over any particular region in a direction determined by the position of the center of the storm to one side or other of the region. If the winds blew undisturbed from the west Wisconsin would not feel the influence of the Great Lakes to any great extent, but, as it is, frequent winds blow from over the lakes onto the lands, bringing large volumes of water in the form of rain or snow. The average rainfall for the whole state is close to 32.3 inches, the major portion occurring in the summer and fall. King (Northern Wisconsin, Handbook for Homeseekers) gives the following figures: Average annual rainfall for the state, 32.3 inches; average for the winter months, 4.7 inches; for the spring months, 7.6 inches; for the summer months, 11.7 inches; for the fall months, 8.3 inches. The distribution through the state is shown by the accompanying maps and climatological

*Harrington's small book "About the Weather" gives a splendid description of cyclonic storms and their effect. Also, full explanation of the daily Weather Map.

table. It will be observed that in the summer and autumn the precipitation is great in the northern part of the state, but in the spring and winter it is heavier in the southern and eastern portion; the heaviest fall of the winter occurs along the borders of Lake Michigan and Green Bay. The average precipitation of snow in the spring and winter is 46 inches in Milwaukee and 46.7 inches at Green Bay, while at Eau Claire it is 19.3 inches, and at Medford 30.4 inches; nearer the shores of Lake Superior the fall of snow is heavier again, 43.5 inches at Grantsburg, and 42.6 inches at Florence.

The Temperature.—The accompanying climatological table is so arranged that the towns on approximately equal east to west tiers appear in succession, enabling a comparison of the climate from north to south and east to west to be made. The maps and the table make at once apparent the decrease in the annual average from the highest, 47.2° at Beloit, on the south line of the state, to the lowest, 40° at Florence on the north line. The influence of the Great Lakes is very striking; on the maps showing the spring months it will be seen that the isotherms for May bend sharply to the south as they approach the eastern side of the state, showing how the chilled waters of the lake hold back the rise in temperature as the spring passes. In the summer months the isotherms pass more nearly directly across the state, but still with a decided inclination to the south, and the isotherm of July, 70°, bends very sharply to the south as it approaches the shore. By fall, as the waters of Lake Michigan are warmed, the isotherms pass almost directly from the land to the water. In the winter, however, the isotherms for January bend very sharply to the north and this bending is felt nearly a third of the way across the state, explaining the long and delightful autumn weather of Eastern Wisconsin.

The influence of Lake Michigan is also shown in the lack of so great a difference between the summer and winter temperatures as prevails in the interior of the state and on its western side. If we contrast Milwaukee with Lancaster, we find they have nearly the same average annual temperature, 45° for Milwaukee and 45.30° for Lancaster, but the average winter temperature of Milwaukee is 38.3° and the average summer temperature is 53.8°, a range of 14.9°, while in Lancaster the range is from 34.4° in winter to 56.2° in summer, a difference of 21.8°, or 7° more than at Milwaukee. The first killing frost at Milwaukee occurs near October 10 and the last near April 29, while at Lancaster the first is near to September 29, 11 days earlier than at Milwaukee, and the last near May 8, 10 days later.

Contrasting Green Bay and Eau Claire, the average maximum of Green Bay is 53° and the average minimum is 35°, a range of 18°; at Eau Claire the average maximum is 54° and the average minimum is 33°, a range of 21°. The earliest killing frost at Green Bay is near October 4 and the last near May 5; at Eau Claire the first is near September 26, 8 days earlier than at Green Bay, and the last is near May 17, 12 days later.

The influence of Lake Superior is shown in contrasting Florence, in Florence county, about halfway between the two lakes, with Washburn, on the shores of Chequamegon Bay, in Bayfield county, over 50 miles north of Florence. The average annual temperature of Florence is 1° lower than that of Washburn to the north. The range of temperature at Florence is from 51° to 29°, or 22°, while that of Washburn is from 50° to 32°, or 18°; the earliest killing frost at Florence is near September 10 and the last near June 1, while at Washburn the earliest is near October 12 and the latest near May 16.

Milwaukee has the highest recorded temperature on the Lake Michigan shore, 100.3°, and Green Bay has the lowest, —36°. Harvey, in Jefferson county, and Lancaster, in the southwestern part of the state, have recorded temperatures of 107, and Stevens Point and Barron have the lowest, —48°. The greatest absolute range recorded is at Neillsville, from 106° to —46°, and the least absolute range is at Oconto, from 99° to —30°.

In general the state has cool summers, not averaging far from 65°, and cold winters, approximately 15°; the portions bordering on the lakes have practically no spring, the cold waters of the lake keeping the temperature down even as far south as Milwaukee until the latter part of May, but the falls are long and delightful, the pleasant weather continuing not infrequently well into November. The damp, chill breezes from the lake in the spring months are perhaps the most disagreeable phase of the climate of the state.

The large number of small inland lakes have very little effect upon the climate, for they are so small that they become thoroughly heated early in the summer and in winter are soon frozen over, so that they exert no modifying influence; their attractiveness as summer resorts depends rather upon the beauty of their surroundings than a cooler temperature.

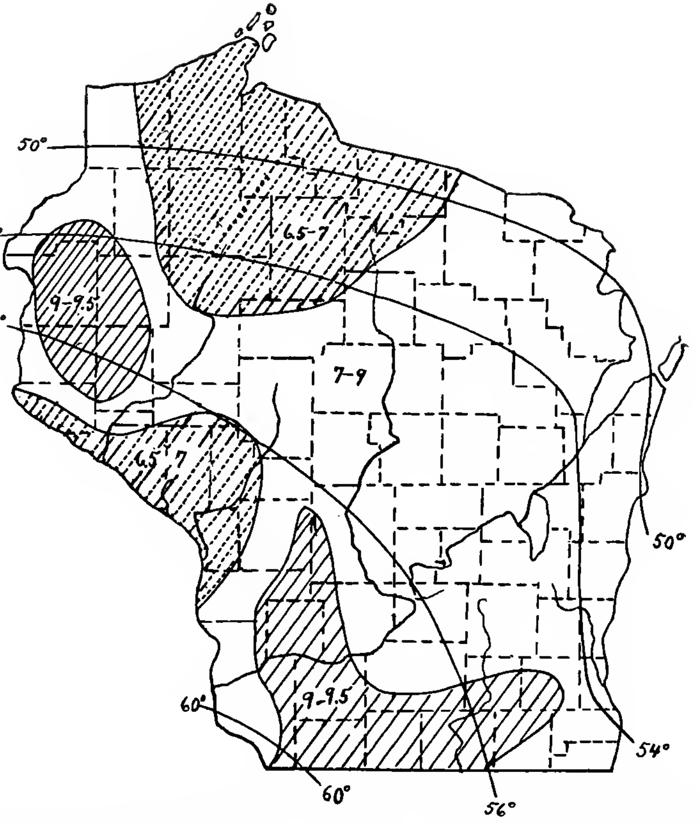


Fig. 46. Climatological map of the state for the months of spring, showing the rainfall in inches and the isotherms. After Henry.

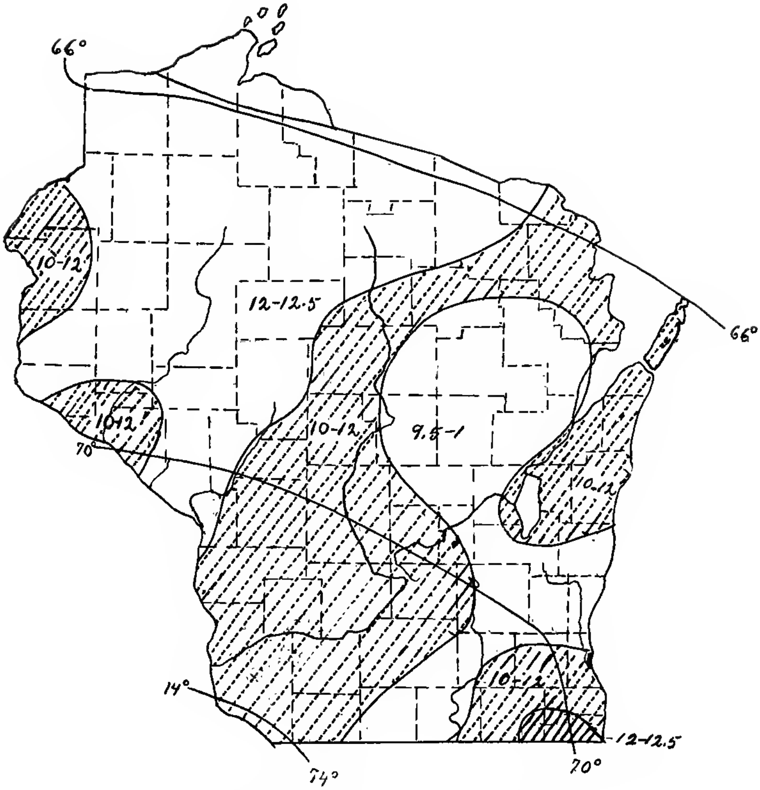


Fig. 47. Climatological map of the state for the months of summer, showing the rainfall in inches and the isotherms. After Henry.

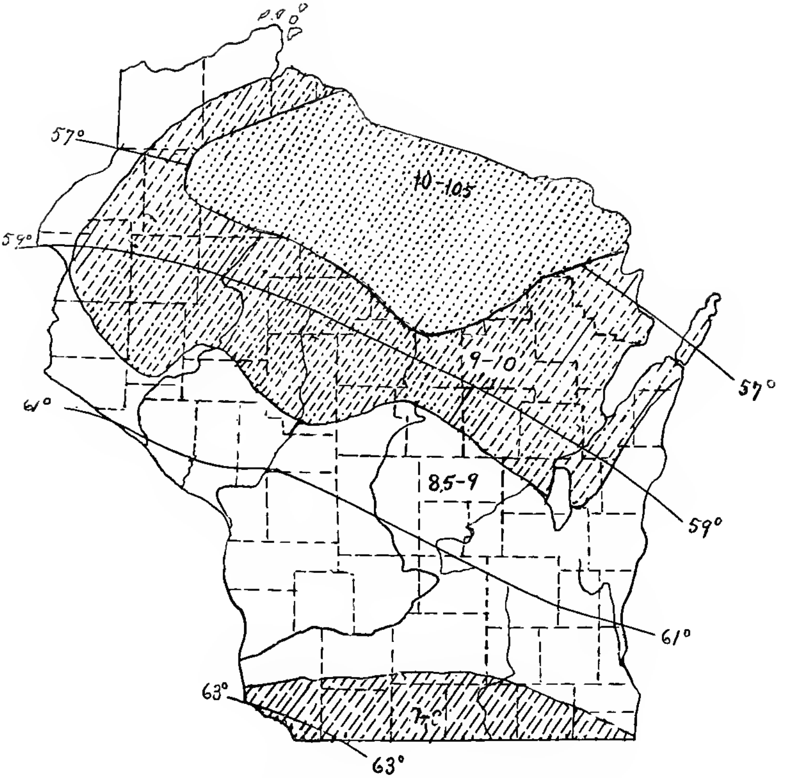


Fig. 48. Climatological map of the state for the months of fall, showing the rainfall in inches and the isotherms. After Henry.

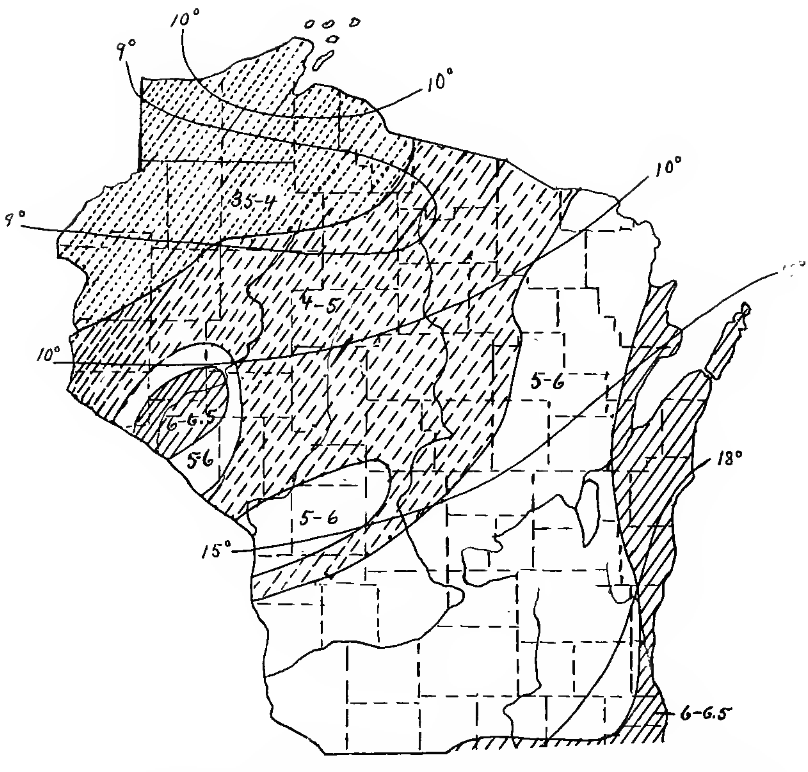


Fig. 49. Climatological map of the state for the months of winter, showing the rainfall in inches and the isotherms. After Henry.

	Madison.	Beloit.	Harvey.	Lancaster.	Milwaukee.	Viroqua.	Hancock.	La Crosse.	Fond du Lac.	Manitowoc.	Stevens Point.
Mean Annual Temperature	45.7	47.2	46	45.3	45	45	45	46.2	45	43	43.7
Mean Maximum Temperature	54	57	56	56.2	53.2	55	54	55.1	55	52	55
Mean Minimum Temperature	37.8	38	36	34.4	38.3	35	35	36.8	35	34	32
Absolute Maximum Temperature	104	105	107	107	100.3	103	100	104	100	100	101
Absolute Minimum Temperature	—29	—25	—24	—29	—25	—31	—35	—43	—30	—32	—48
Average date first killing frost	Oct. 13	Oct. 10	Oct. 1	Sep. 29	Oct. 10	Sep. 26	Sep. 24	Oct. 8	Sep. 29	Oct. 11	Sep. 22
Average date last killing frost	Apr. 21	Apr. 23	May 4	May 8	Apr. 29	May 10	May 16	May 2	May 11	May 12	May 24
Mean annual Precipitation (inches)	31.4	32.8	31.7	32.5	31.0	36.4	28.3	30.9	26.2	30	28
WINTER.											
Mean Temperature	20.1	20.8	19.5	17	22.7	17	17	19.4	19	20	16
Mean Maximum	26.2	29.3	27.1	26.3	29.9	25	25	26.7	27	28	26
Mean Minimum	12.0	12.3	11.9	7.5	16	9	9	10.3	11	12	6
Mean Precipitation (inches)	4.8	5.6	4.1	3.4	5.80	4.3	3.5	3.55	3	4.9	2.5
Average Depth Snow (inches)	19.7	22.2	6.2	....	35.8	25	25.5	26.2	16.7	23.2	20.1
Prevailing Wind Direction	N. W.	W.	N. W.	N. W.	W.	N. W.	W.	S.	N. W.	N. W.	N. W.
SPRING.											
Mean Temperature	44.3	47.5	46	46.1	42.7	45	45	46.1	45	41	44.1
Mean Maximum	54.4	57.1	56.5	53.7	51.7	55	55	55.3	55	50	55
Mean Minimum	36.3	37.9	35.7	35	36.5	35	34	36.6	35	32	33
Mean Precipitation (inches)	7.6	8.5	8.9	8.6	8.5	10.6	7.8	7.5	6.5	7.2	7.9
Average Depth Snow (inches)	.7	5.3	2.3	....	10.2	12.1	9.8	9.1	7.7	8.5	12.2
Prevailing Wind Direction	S.	S.	S. W.	E.	N. E.	S. W.	W.	S.	S. W.	N. E.	N. W.
SUMMER.											
Mean Temperature	69.8	70.9	69.9	70.4	67.4	69	69	70.8	68	65	68
Mean Maximum	79.8	81.8	81.9	82.8	73.2	80	81	80.6	80	75	81
Mean Minimum	61.5	60	57.6	39.7	59	57	58	60.5	56	54	55
Mean Precipitation (inches)	11.3	11.3	10.8	10.4	9.5	13	11.1	11.9	10.2	10.2	9.8
Average Depth Snow (inches)	0	0	0	....	0	0	0	0	0	0	0
Prevailing Wind Direction	S. W.	S. W.	S. W.	S. W.	S. W.	S. W.	W.	S.	S. E.	S. E.	S. W.
FALL.											
Mean Temperature	48.2	49.5	48.7	47.8	48.8	48	48	48.7	49	47	46.5
Mean Maximum	57.1	58.2	58.6	58.6	57.1	58	57	57.7	58	55	57
Mean Minimum	41.5	40.8	38.8	37	42.7	38	38	39.7	39	38	36
Mean Precipitation (inches)	7.6	7.4	7.8	7.1	7.2	8.5	5.9	8.1	6.5	7.7	7.8
Average Depth Snow (inches)	3.2	4.8	....	....	4.7	5.8	4.4	4.6	4.3	4.2	....
Prevailing Wind Direction	S.	S.	S. W.	S. W.	S. W.	N. W.	W.	S.	S. W.	S. W.	N. W.

*Climatological table of Wisconsin from data furnished by U. S. Weather Bureau.

	Green Bay.	Oconto.	Koepenick.	Medford.	Eau Claire.	Neillsville.	Grantsburg.	Hayward.	Barron.	Florence.	Washburn.
Mean Annual Temperature..........	44	44	42	42	44	43	42.5	40.8	42	40	41
Mean Maximum Temperature........	53	55	53.1	55	54	53	55.6	53.1	52	51	50
Mean Minimum Temperature........	35	33	28	29	33	32	29.4	28.4	31	29	32
Absolute Maximum Temperature.....	99	99	....	103	103	106	105	102	102	98	104
Absolute Minimum Temperature......	—36	—30	....	—45	—40	—46	—45	—43	—48	—39	—33
Average date first killing frost......	Oct. 4	Sep. 29	Sep. 15	Sep. 11	Sep. 26	Sep. 16	Sep. 22	Sep. 9	Aug. 31	Sep. 10	Oct. 12
Average date last killing frost......	May 5	May 14	May 9	June 2	May 17	May 15	May 20	June 8	May 31	June 1	May 16
Mean annual Precipitation (inches)..	31	29.3	34.9	33.3	33.7	34.2	31.1	32.9	30	31.5	29.8
WINTER.											
Mean Temperature	18	19	14.7	14	15	14	14	13.5	12	15	16
Mean Maximum	26	29	26.9	25	24	22	26.4	24.1	23	24	24
Mean Minimum	11	10	2.3	3	6	6	1.7	.3	2	6	8
Mean Precipitation (inches)........	5.3	4.1	3.7	2.8	3.8	3.7	3	3.4	3.2	3.4	4
Average Depth Snow (inches).......	38.6	31	28	20.4	13.5	21.6	27	....	28.3	27.3	38.1
Prevailing Wind Direction..........	S. W.	W.	N. W.	W.	....	N. W.	N. W.	S.	N. W.	N. W.	....
SPRING.											
Mean Temperature	42	43	42.3	41	44	44	42.1	41.2	41	39	37
Mean Maximum	51	55	59	55	55	55	56.5	54.2	53	51	47
Mean Minimum	33	31	29	28	32	32	28.7	28.2	30	28	28
Mean Precipitation (inches)........	8.1	8.4	9.2	8.5	9.3	9.4	8.8	7.3	8	9	6.7
Average Depth Snow (inches)......	13.6	13.5	20.1	10	5.8	13.3	16.5	....	10	15.3	20.5
Prevailing Wind Direction..........	N.	N. E.	S. W.	W.	....	N. W.	E.	S.	S. E.	S. W.	....
SUMMER.											
Mean Temperature	42	67	66.7	67	68	68	67.3	66.5	67	64	66
Mean Maximum	51	79	79	84	80	81	81.4	79.8	80	77	76
Mean Minimum	33	55	49	51	51	55	53.4	53.2	52	51	55
Mean Precipitation (inches)........	9.7	9	11.9	12.6	11	12.5	11.1	13.5	11.3	10.7	9.2
Average Depth Snow (inches)......	0	0	0	0	0	0	0	....	0	0	0
Prevailing Wind Direction..........	S. E.	S. E.	S. W.	W.	....	N. W.	S. W.	S.	S. W.	S. W.	....
FALL.											
Mean Temperature	47	48	45.3	44	43	46	46.6	43.2	47	43	46
Mean Maximum	56	58	57	56	57	56	59.3	54.3	54	53	54
Mean Minimum	39	37	32	32	36	36	34	32.1	39	33	38
Mean Precipitation (inches)........	7.9	7.8	10.1	9.4	9.6	8.6	8.2	8.6	7.5	8.4	9.9
Average Depth Snow (inches)......	7	11.1	....	5.7	3.1	5.8	8.6	....	6	11.3	10.1
Prevailing Wind Direction..........	S.	S.	S. W.	W.	....	N. W.	N. W.	S.	S. E.	N. W.	....

CHAPTER XI.

THE SOILS OF THE STATE.

The soils are perhaps the most difficult portion of any region to describe, for the complication of their structure and content and the infinitely small shades from one variety to another renders any attempt at a rigid and simple classification impossible. The subject is far too complex for a general description and only the broadest outlines of the subject can be attempted.

Repeated efforts have been made to determine upon a fixed classification of soils which would stand the test of all demands made upon it, but none have as yet reached any very general acceptance. They may in a general way be classified as to their origin and as to their composition.

Origin. — Soils are spoken of as local, sedentary, or residual, when they have been formed from the decay of the rocks in the very region where the soil is found or at no very great distance from it; as, the soil of a river bottom, which may be derived from an adjacent bluff or upland. A soil that has been carried a long distance from its place of origin and spread upon the surface of the ground in a new locality is spoken of as a transported soil; the classical example is the soil brought from Canada by the glaciers and spread out upon the surface of the United States south of the Great Lakes. This soil is commonly referred to as the "drift." Other transported soils are carried by rivers and deposited from water; they are called "alluvial soils." The drift is typically unstratified, as would be expected from its mode of origin, and the alluvial soils are stratified or sorted.

Composition. — In the classification by composition an almost endless number of terms have been invented and used. A few of those in common use are defined for the purposes of more intelligent description and appreciation.

A gravelly soil consists of fragments of stones of greater or less size with some smaller amount of fine material; the latter does exceed 30 per cent.

The sandy soil has at least 80 per cent of sand grains. The grains are usually of quartz, so that sand has come to be almost synonymous with quartz grains, but the grains may be of other substances, as fragments of granite or other rocks, grains of coral or iron, etc. Glauconitic sand is composed largely of small grains of the mineral glauconite, which contains much phosphorus and is used as a fertilizer. From its color it is commonly spoken of as "green sand."

Clay soils contain at least 60 per cent of clay and the residue may be sand or other product of rock decay.

Loam soils contain much of both sand and clay, and the proportions of the two may vary widely. According to Stockbridge (Rocks and Soils. New York, 1895), a "heavy clay loam" has only 15 to 25 per cent of sand; a "clay loam" has 25 to 40 per cent of sand; loam has 40 to 60 per cent of sand; "sandy loam" has 60 to 75 per cent of sand; "light sandy loam" has 75 to 90 per cent of sand.

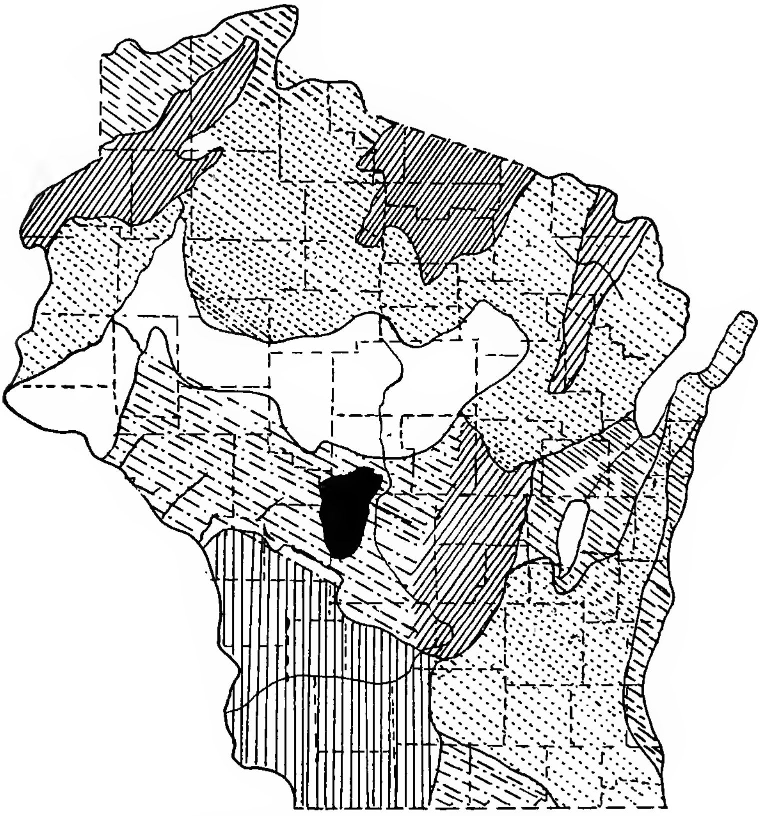
Marl is a very calcareous or "limey" clay. Its calcium carbonate must constitute at least 15 per cent of the soil and the clay at least 75 per cent.

Mucky or humus soils contain a large amount of decayed vegetable matter called humus. The proportion of humus may be so great that the soil is practically all vegetable fiber, and then it is called peat.

Loess is a fine, light yellow, gritty soil, composed largely of clay, but containing considerable quantity of calcium carbonate in the form of minute tubles or casts extending through it. It is supposed to have originated largely as wind-blown material, collecting in lakes or pools of shallow water or on the surface of the ice.

Origin of the Soils.—The soils originate from the disintegration of the solid rock by the various forces which act upon the rocks to their destruction. Prominent among these is the frost; when the moisture of the air penetrates down into the cracks in a rock and freezes, the expansion of the solidifying water is powerful enough to split the rock to fragments and split the finer fragments still finer, even to microscopic proportions. It is largely for this reason that the farmer plows his land and lets it lie fallow during the winter. After the frost comes the solvent action of the water containing oxygen and carbon dioxide or "carbonic acid gas"; both of these gases when present in the water render it very active in taking up parts of the rock and loosening the whole mass by its action. The alternate expansion and contraction of the different minerals, especially in the igne-

ous rocks, under the cooling and heating of night and day, produces a considerable amount of rupturing and fracturing of the stones. Finally the growing and expanding plant roots, forcing their way into the crevices of the solid rock, do a considerable amount of work in splitting them up into smaller particles.



General Soil Map of Wisconsin after Whitsun.

Oblique lines, sands of later drift. Vertical lines, residuary clay of driftless area. Dotted lines, clay of later drift. Broken line, lake clays. Dot and dash, sands from Potsdam sandstone. White, clay of earlier drift. Black, muck or peat.

Fig. 50. Map showing the soils of the state, in a very broad way. White, sandy soil. Broken lines, light clay loam. Dotted lines, heavy clay loam. Solid lines, lake clays.

The disintegration of the igneous rocks, as granites, dolerites, gneisses, schists, etc., afford considerable amount of clay from the decomposition of the feldspars and hornblendes, while the quartz remains as sand; the decomposition of limestone results in the solution and carrying away of the calcium carbonate, leaving behind a mass of residual insoluble matter which is largely clay; the growth of abundant vegetation on a soil, as in a swamp or heavy forest, introduces the humus into the soil.

The Soils of the State.—In general the driftless area and a considerable part of the drift covered area of Southeastern Wisconsin is covered with a clay loam derived from the decomposition of the limestone and the accumulation of the residual clay. In the central and western portions of the state, which are underlain by the Potsdam and St. Peter's sandstone, the soil is a sandy loam, except where the later drift deposits have obscured the true soil. In the strip running northeast and southwest in the Green Bay lowland west of the Niagara cuesta and underlain by the Cincinnati shales, the soil is a clay, but contains a considerable quantity of sand and lime derived from the shales from which it originated. Bordering the edges of the Great Lakes there is a heavy deposit of a red clay which is mixed with enough lime to form a marly clay soil of a medium or rather heavy character. The much mixed drift soil of course overlies all of the state within the limits of the terminal moraine.

The Soils of Eastern Wisconsin.—The following description of the soils of the eastern part of the state, with the definition of the varieties, is taken from the report of the First Survey:

Class 1. The Prairie Loam. This sometimes arises from the decomposition of the underlying limestone, sometimes from the disintegration of limestone gravel, and sometimes it arises from the deposits of an ancient lake. There are several varieties, but all have at least a moderate degree of fineness of texture, while some manifest this quality in a very high degree. It is a warm soil, but not so rich as its blackness might lead one to suppose, yet very responsive to the proper fertilizers. Vegetable matter in the form of humus penetrates this soil to greater depths than in most of the following classes, and imparts to it a darker color. The areas occupied by it are mainly confined to the southwestern third of the district under consideration, or, as it happens, perhaps casually, to the Mississippi basin.

Class 2. The lighter Marly Clay Soils or Clayey Loams. These are drift soils, having been derived chiefly from a calcareous boulder clay, which in turn was formed by the powder-

ing of various kinds of rocks, but chiefly magnesian limestone, by glacial agencies. Much of the lime and magnesia has been leached out from the surface layers, but the subsoil is highly calcareous. There is just enough of the sandy material in it to make it loamy. The dark vegetable material does not penetrate as deeply as in the prairie loam, so that the plow frequently turns up the reddish or yellowish subsoil containing very little humus. The soil works with the utmost facility and is unsurpassed in this respect. It stands both wet and drought well and is a very durable and fertile soil. This class graduates into the sandy loams on the one hand, and the heavier clayey loams on the other. It prevails in the same general region as the prairie loams, its areas being irregularly interwoven with them.

Class 3. The heavier Marly Clay Soils or heavier Clayey Loams. This class is similar to the preceding, both in character and origin, but contains a much larger clay constituent, as the drift from which it was derived contained a larger number of Archean boulders, which furnished clay by their disintegration, and less of the limestone. The soil is colored by a large proportion of iron oxide and the waters are strongly impregnated with it; if a magnet is drawn through the finely powdered soil it brings out a considerable quantity of magnetite, derived from the crushed Archean rocks. The vegetable mould is confined mainly to a few inches at the surface. This is the prevailing soil in the heavily timbered regions of the central portion of Eastern Wisconsin.

Class 4. The Red Marly Clay Soils. The red clay is an impure clay formed by deposit in the bottom of the lakes in their wide postglacial extent. The clay is far from pure, containing much of silica, calcium carbonate and small fragments of quartz and limestone. Physically it acts like a clay in that it is very fine, close, compact, adhesive, and almost impervious. It washes readily when wet, but drys stiff and hard and cracks into roughly cubical blocks. It occupies a belt along Lake Michigan, from Milwaukee to Sturgeon Bay, widening to the northward, and spreads widely at the head of Green Bay. In other words, it occupies the region formerly covered by Lake Michigan and the glacial Lake Nicolet.

Class 5. The Humus or Mucky Soils. They are accumulations in the swamps and lowlands of large quantities of vegetable materials, which, as the swamps are drained, become dry enough to permit an abundant vegetation. Where they contain a sufficient admixture of clay or sand they are very fertile. At times the accumulated vegetable material contains a considera-

ble amount of acid derived from the decaying vegetation, so much that vegetation is hindered; these are the sour soils and will not support cereals or the higher grasses.

In Central and North Central Wisconsin the soil is determined by three things in particular: The drift, the underlying sandstone, limestone and Archean rock. "The drift soils are either bad or good, as the material is more largely sandy or shows a predominating admixture of clayey and calcareous substances; those resulting solely from the disintegration of the sandstone of the poorest quality, while the limestone soils are usually the best in the region. The crystalline rock soils are often good, but as the region of crystalline rocks is nearly everywhere invaded by the drift, its soils are commonly dependent upon the nature of the drift, rather than that of the subadjacent rock. In some portions of the Archean region, where either the drift is not present in very large quantity and the feldspathic rocks have disintegrated into a good clay soil, as in the high land in the western part of Marathon county, or where the drift itself is of a non-arenaceous character, as in much of Clark county, and in many places along the line of the Wisconsin Central Railroad, excellent lands for farming have been made by clearing away the growths of hardwood timber. (Since this was written the clearing of the land of North Central Wisconsin has progressed at a rapid rate and the old timber lands have become a great farming region.) Where the drift is more sandy, as in a large portion of the region around the headwaters of the Wisconsin river, the land is worthless for agricultural purposes. Through the sandy nature of the drift material the sand region of Central Wisconsin extends in places far beyond the district occupied by the Potsdam sandstone. In all of the region in which the last named rock is the surface formation, and where the drift is either absent or present in small quantities only, or is altogether sandy in nature, as in most of Adams, Juneau, Sauk, Jackson, Marquette and Waushara counties, in much of Columbia, and in places all along the valley of the Lower Wisconsin, the soil is generally a loose sand, and the land of the poorest quality. Where the drift overlies the sandstone and contributes clayey or calcareous matter, as in the southern part of Adams county, or the eastern part of Waushara, the land is often good. In other cases, a good soil within the Potsdam area and where the drift is absent, seems to have resulted from the filling of the valleys with fine stream detritus, as along the valley of the Wisconsin; or nearness to the surface of certain clayey layers included within the sandstone, as in the town of Reedsburg, Sauk county; or from the presence

of considerable dolomitic material in the sandstone, as in the town of Honey Creek, Sauk county. All these are, however, but exceptions to the general rule that, for the most part, the Potsdam areas, on both sides of the drift limit, is a barren, sandy region."

The soils of North Central Wisconsin have been the subject of special investigation by Weidman (Soils of North Central Wisconsin. Bull. XI, Geol. Survey of Wis.). He distinguishes a large variety of soils, the loams and sandy loams of the drift being the most common. It is largely determined by the drift materials, but is influenced in places by the bed rock, as the Potsdam sandstone, which occasionally gives the clay a decidedly loamy character from the admixture of sand.

The soil of Southwestern Wisconsin is a local or residual soil and is almost entirely dependent upon the decay of the underlying rocks, as it is without the limit of the drift. The most common soil south of the Military Ridge is a clay from three to six feet in depth derived from the decomposition of the Hudson River shales, which once covered the region, and from the upper portion of the Galena limestone. In the eastern part of Lafayette and in much of Green county, the Galena limestone contained considerable sand and the disintegration and removal of the calcium carbonate has resulted in the concentration of the insoluble sand to such an extent that the whole region appears to be a sandstone area, the roads and soil resembling those of a portion of the Potsdam area to the north.

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